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Soil Bio- and Eco-engineering
The Use of Vegetation to Improve Slope Stability

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Book of Abstracts

TALKS

TALK

Comparing Mediterranean and non-native plant root architecture for slope stabilisation in Italy: laboratory studies and qualitative analysis

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Plants interact significantly and dynamically with soil, water, and atmosphere, influencing slope stability and deformation processes through root reinforcement, modulation of the hydrological regime, and alteration of microclimatic conditions. For this reason, vegetation has long been used to enhance soil improvement, reduce erosion, and regulate water flow. However, the success of these interventions depends on carefully selecting plant species that are well-suited to the specific environmental conditions and challenges of the site, as well as understanding how their growth and root systems will evolve to provide lasting stability over time.
This study analyses the root architecture of native Mediterranean plant species in Italy, such as Laurus (*Laurus nobilis L.)*, and Buxus (*Buxus sempervirens L.*) and compares them with non-native species used in bioengineering, such as Vetiver (*Chrysopogon zizanioides, (L.) Roberty*) and Bamboo (*Phyllostachys aurea (André) Rivière & C. Rivière*).
In the laboratory studies here presented, plants were cultivated in separate boxes, positioned outdoors, with a sheet of geosynthetic material placed a few centimetres beneath the soil surface to ensure that the roots would reach it and spread across its mesh. This setup was implemented to create a uniform surface, represented by the geosynthetic itself, onto which the plant roots could distribute evenly, allowing for the analysis of their architectural pattern. After approximately 8.5 months, the plants were removed from the cultivation containers, and the soil was gradually removed with water. The root systems and geosynthetic material were visually inspected, with the geosynthetic being separated from the plant by cutting the roots 5–10 mm from the surface of it. Differences in root penetration, density, spatial distribution, and root network development were analysed for each plant species, to better inform a plant selection for sustainable slope stabilization.

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TALK

Mitigating soil erosion with vegetative barriers in Belgium's open agricultural landscapes

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Vegetative barriers are a nature-based solution to reduce sediment export from croplands, mitigating the negative off-site impacts of soil erosion. This study evaluates the effectiveness of vegetative barriers implemented in Flanders (Belgium) in buffering water and sediment flows. The study assessed the current condition, sediment-retention capacity, and peak flow buffering performance of vegetative barriers at a regional scale. Within an area of 1,154 km^2, 40 vegetative barriers, composed of four different plant-based materials, were randomly selected from a total of 207 barriers for assessment. The condition of each barrier was evaluated, and GNSS measurements were done to calculate their runoff retention capacity. Long-term sediment influx and peak runoff were modelled per vegetative barrier. A strong correspondence between field-derived Digital Elevation Models (DEMs) and high-resolution DEMs from public databases enabled calculating the sediment retention capacity and peak flow buffering performance for all 207 barriers. Results indicated that over half of the visited vegetative barriers were found to be completely dysfunctional. Key issues include inadequate maintenance, decomposition, and human interventions such as removal, relocation, or perforation. Additionally, soil piping was observed in 20% of locations, further reducing effectiveness. Barrier condition varied significantly by type, with coconut-fibre bale barriers in the poorest condition and woodchip barriers in the best. The majority of barriers lack sufficiently large retention ponds to capture one year’s sediment deposition, even under optimal technical conditions. Moreover, half of the barriers were found to be ineffective at buffering peak flows during severe weather events. This ineffectiveness is largely attributed to poor maintenance. In contrast, well-maintained barriers are capable of managing peak flows relatively effectively. We conclude that while vegetative barriers represent effective nature-based solutions for erosion mitigation, significant challenges persist in their implementation and maintenance.

Keywords: Nature-Based Solutions, Runoff, Soil Loss, Soil Conservation

TALK

The Effect of Live Pole Drains (LPDs) on Subsurface Lateral Drainage Performance: a lab-based approach

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Live pole drains (LPDs) are sustainable drainage systems consisting of live fascine bundles inserted in shallow drainage trenches. LPDs can be built with locally available materials and hand tools, being ideal solutions to drain slopes in remote sites under resource-limited situations. However, the performance of LPDs has not been studied in relevant detail. We designed a pilot, lab-based study to investigate (i) the effect of LPDs on subsurface lateral drainage, (ii) the influence of the LPDs' morphological traits on drainage performance, and (iii) the sensitivity of plant-soil parameters affecting drainage performance. We established two laboratory experimental treatments (i.e. basket-willow (*Salix viminalis sp.*) LPDs (n=18) and fallow soil as control (n=12) specimens) under controlled environmental conditions of light, moisture, and temperature. The total duration of the experiment was 2 months. After the development of new willow shoots and roots in the LPD treatment, we measured subsurface lateral drainage in both treatments on days 18, 32, and 46 from the start. To this end, we built a novel experimental setup consisting of a water tank, hydraulic fittings, and a pipe valve (Fig1). We measured flow rates at the pipe outlet using a volumetric cylinder and stopwatch (Fig2). We observed flow distribution inside the specimens using a dye solution, cutting them into five cross-sections along their length, taking pictures of each cross-section, and then analysing the images to determine the water flow area (Fig3). We also measured the soil matrix porosity, root density, and root distribution through image analysis (Fig4). The comparison of subsurface lateral drainage performance between LPD and control specimens showed that root development positively impacted subsurface lateral drainage flow over time by increasing the flow cross-sectional area with respect to the control. This research will lay a solid foundation for the theory underpinning the eco-hydrological performance of LPDs, and it will open an exciting opportunity to undertake future studies at the plot scale seeking to shed light on the design, replication, and upscaling of LPD for slope drainage and stability.

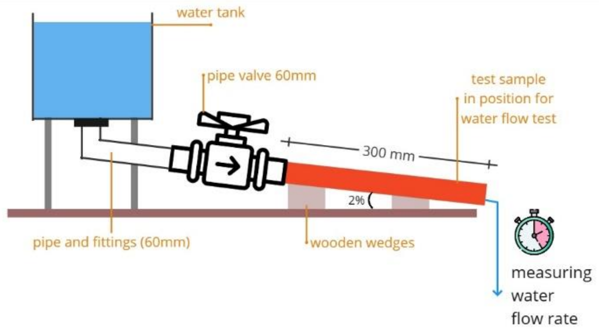

Fig 1 - schematic elevation lab setup for water flow test


Fig 2 - water flow test

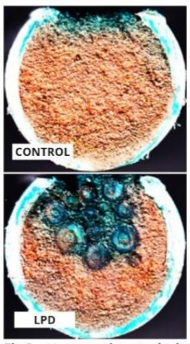

Fig 3 - cross-section analysis

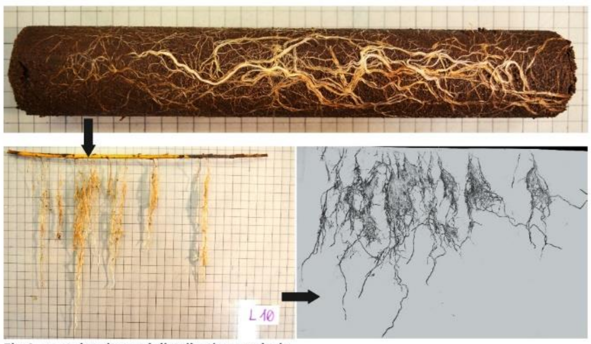
Fig 4 - root density and distribution analysis

TALK

Integrating Vetiver-based Nature-based Solutions for Sustainable Slope Stability and Ecosystem Resilience

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Nature-based solutions (NBS) are emerging as sustainable alternatives to traditional engineering by leveraging ecological processes to enhance resilience and mitigate disaster risks. This study explores the application of vetiver grass (Vetiveria zizanioides) as a bioengineering tool to improve slope stability and deliver multiple ecosystem services. Vetiver's dense, deep-rooted system promotes soil cohesion, increases water infiltration, and minimizes erosion, thereby reducing landslide hazards—a critical aspect of disaster-risk reduction. Simultaneously, its use contributes to ecosystem-based adaptation by enhancing biological richness and structural diversity, providing habitat for diverse flora and fauna, and reinforcing nature's contribution to people. Field implementations in tropical landscapes demonstrate that integrating vetiver systems not only stabilizes slopes but also supports sustainable land management and community resilience. Our findings underscore that vetiver-based interventions are cost-effective, low-impact strategies that bridge conventional engineering and ecological conservation. Future research will focus on optimizing planting configurations and management practices to further exploit the multifunctional benefits of NBS in varied geomorphological settings.

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TALK

Urban expansion, vegetation loss and landslide risks must be addressed to ensure the sustainability and safety of Xalapa, Veracruz, Mexico.

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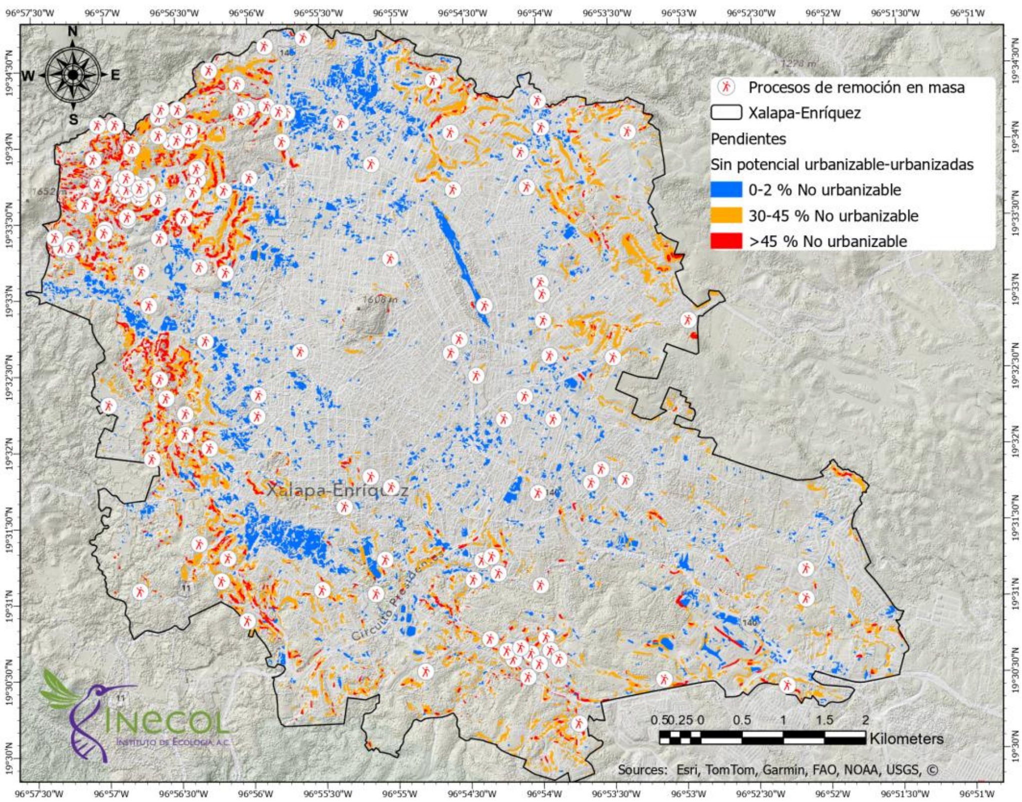
In Latin America, the conquest led to the establishment of urban centres, with around 200 by 1550, many located at elevations between 2,000 and 4,000 meters. Urbanisation occurred on steep slopes without regard for environmental guidelines, adversely affecting residents, ecosystems, and biodiversity. SEDATU (2019) provided urban planning guidelines for Xalapa, focusing on topography and recognising slope as a key criterion for construction suitability. This study assesses both authorised and unauthorised urban expansion in Xalapa, Veracruz, evaluating territorial suitability based on slope and land use to highlight residents' vulnerabilities. The city's polygon of Xalapa-Enríquez was obtained from INEGI (2023) through the Geostatistical Framework 2023. High-resolution terrain data, specifically LIDAR digital elevation models at 5-meter intervals, were sourced from the Mexico Space and Data Query System (INEGI, 2024). Revealing that urbanisation on steep slopes increases risks such as landslides, particularly following vegetation removal. In the city of Xalapa, 134 mass removal processes were identified from 2014 to 2024 (SPC, 2025), primarily attributed to the type of soil (unconsolidated) and the absence of vegetation cover. Existing regulations to mitigate these risks are poorly enforced. The urbanisation potential based on slope indicates that areas marked in red are unsuitable for development, primarily located in the city's northwest and southwest, including important remnants of cloud forest. To safeguard inhabitants and the environment, cities must adopt risk management strategies and sustainable urban planning practices, such as reforestation and restoration practices, to address these challenges and protect their inhabitants and the environment.



TALK

Quantifying the spatio-temporal mechanical reinforcement effects of the pioneer species *Betula pendula*: experiences from a case study in Western Norway

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Protection forests have gained recognition as Nature-based Solutions (NbS) for preventing shallow landslide triggering, as trees can enhance slope stability through both hydrological and mechanical processes. In Western Norway, natural regrowth of deciduous forests is occurring due to reduced agricultural activities in the region. This study aims to quantify the mechanical reinforcement effects of the pioneering tree species *Betula pendula* at a case study site in Western Norway. An extensive field and laboratory campaign was conducted, enabling the calibration of a spatio-temporal root reinforcement model for stand-scale applications. Additionally, the study explores the impact of human intervention on tree growth, and consequently root reinforcement, comparing data from naturally growing and pollarded trees. The estimated reinforcement effects of *Betula pendula* using the root bundle model with a Weibull survival function (RBMw) fall within the range of other tree species assessed with the same methodology and reported in the literature. The resulting model performs well in predicting the spatio-temporal variation of root reinforcement for Norwegian birch forests. It was found that pollarded trees take longer to achieve the same reinforcement effect as naturally growing trees, suggesting that pollarding should be avoided in protection forests. This collection and application of the obtained dataset represents a pioneering effort in Norway, being the first dataset developed for any type of forest in the country. The findings highlight that the establishment of protection forest for landslide risk reduction is a long-time perspective measure, which requires thorough planning and adequate maintenance to ensure success.

Keywords: *Betula pendula*, Root reinforcement, Protection Forest, Forest management, NbS, Time dependency, Shallow landslides.

TALK

Soil and water bioengineering techniques: ancestral Nature based Solutions meeting the challenges of the Anthropocene

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Soil and water bioengineering techniques (SWBE) have a long history and have been developed extensively since the Renaissance. In the 19th and early 20th centuries, very ambitious, complex and large-scale structures were built to channelize large rivers and protect their banks, or to stabilize large-scale erosion in the Alps.

These techniques were largely forgotten after the Second World War, and then revived in the 80s and 90s. But current feedback shows that we're doing things more simply and less ambitiously than in the past. However research has demonstrated the ability of SWBE to stabilize embankments and banks very effectively over time, while maintaining biodiversity and the associated ecological services.

Faced with the Anthropocene, these age-old techniques still face a number of challenges. Efforts are still needed to refine the elements of dimensioning, to disseminate these techniques in areas where they are not yet available, but also to better explain the ecological services provided, and to better take into account the social dimension, including health. In addition, we need to develop more adaptive, low-tech approaches that are less expensive, less destructive and consume less carbon. The advance of global change, including climate change and biological invasions, should also lead us to rethink these techniques.

It's all about changing the paradigm by adopting a caring and cooperative approach to nature. This way of practicing SWBE benefits from being transdisciplinary and holistic, from the thought of the relationship between man and nature right through to the completion of the project, i.e. from philosophy to the pickaxe. Some examples show that this approach is also a source of hope, collective dynamism and joy.

TALK

Exploring stress-paths and vegetation reinforcement mechanisms in a clayey sand

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The use of vegetation is a sustainable technique to mitigate the risk of landslides and erosion phenomena. The reinforcement of roots on soils is complex and depends on their morphological and mechanical characteristics and the stresses that develop at the soil–root interface. Many models have been produced in literature to infer the increase in soil shear/tensile strength due to roots. Among them, soil hydraulic state was poorly considered. Large cell triaxial consolidated drained compression tests and uniaxial tensile tests (figure 1) were carried out to explore the mechanical effects of vegetation on a compacted soil at low confining stresses and at different hydraulic states (in terms of suction and degree of saturation). Root features were assessed through X-ray tomography for each soil specimen and correlated, jointly with soil hydro-mechanical states, to the two soil reinforcement mechanisms observed (roots breakage and slippage). Different stress-strain responses were observed during the mechanical tests, depending on soil initial suction. Despite an increase in shear strength, vegetated specimens showed larger volumetric deformations upon shearing. Strain spatial distributions during tensile tests were observed by Particle Image Velocimetry: roots redistributed the tensile stresses over larger soil volumes. A combination of two literature reinforcement models was adopted to interpret the results: one model to consider root tensile strength full exploitation and breakage, and the other to predict friction forces at the soil–root interface during root slippage. The correlation coefficients of these two models were calibrated based on this experimental campaign.

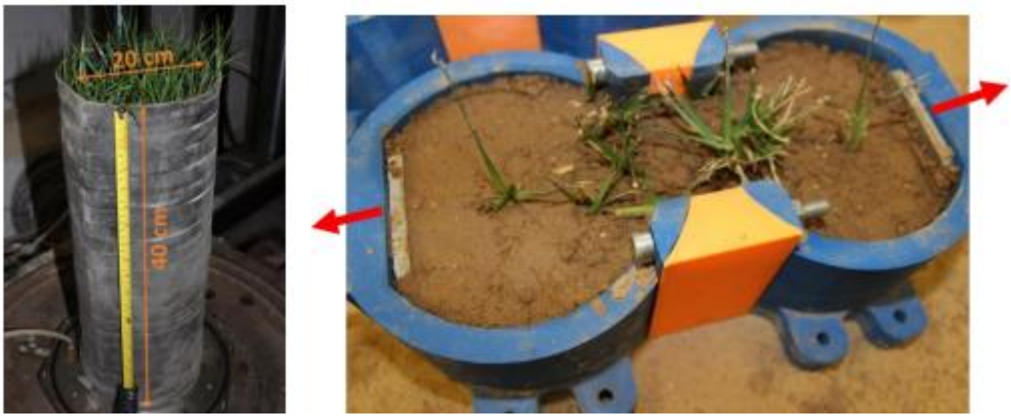

Figure 1 a) Large cell triaxial specimen; b) uniaxial tensile test apparatus and specimen

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TALK

Using plant-based eDNA for identifying the origins of sediment in two contrasting catchments: a lowland agricultural area and a high mountain environment characterized by semi-natural vegetation

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Sediment source fingerprinting is a valuable technique for tracing the origins of sediment. Since geomorphological processes are closely linked to vegetation type and cover, understanding sediment production associated with different vegetation types can greatly aid catchment management. This study explores the potential of environmental DNA (eDNA) as a sediment tracing tool in two contrasting catchments: a lowland agricultural region and a high mountain environment with semi-natural vegetation. Using a barcoding approach, eDNA analysis targeted plant species in samples from representative land cover types and river sediments collected during four flood events. Data analysis involved quantifying eDNA concentrations, visualizing community composition differences with Non-metric Multidimensional Scaling, and identifying indicator species for various vegetation types. The findings confirm that soils contain an eDNA signal reflective of their vegetation cover, even in highly degraded conditions such as eroded soils. For sediment samples, some flood events supported the proof of principle - for instance, erosion from a *Solanum tuberosum* L. (potato) field contributed to the eDNA signature in lowland agricultural sediments, while vegetation from degraded ski runs and heathland dominated the eDNA signal in a high mountain flood event. However, results from other events were less conclusive. While eDNA fingerprinting shows great promise for sediment source tracking, its effectiveness depends on the methodological approach and the specific application context.

Keywords: amplicon sequencing, cropland, mountain, sedDNA, soil erosion, trnL, vegetation

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TALK

Assessment of scour depth in meandering rivers : towards improved design of soil and water bioengineering protection structures.

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Erosion is essential to the proper functioning of watercourses and the preservation of their mobility space. However, when human stakes are high, it may be necessary to stabilize the banks with protective structures. Unlike civil engineering, soil and water bioengineering techniques have the advantage of preserving biodiversity and the associated ecosystem services. In practice, these techniques are mainly designed based on expert opinion and promoted through field feedback, and lack of precise, operational dimensioning elements.

This study focuses on the assessment of scouring depth in meanders, which is a major process in the destabilisation of these structures. Topography and granulometry are measured on one hundred and sixteen meanders in south-east France. The results given by existing formulas are compared with field measurements on small and medium rivers for a more accurate estimation of this depth according to the morphological context of the site. The sensibility of the parameters of each formula is also analysed in order to examine the relative weight of the hydraulic and geomorphic characteristics on scour. The influence of parameters such as curvature radius, width of flow, slope or granulometry is discussed in the light of the sensibility analysis and field data.

These results provide an initial overview of the range of validity, advantages and disadvantages of each formula, making it easier to size meander scouring depth and consequently to design soil and water bioengineering structures accordingly. Some examples of soil and water bioengineering protection structures are proposed to limit the effects of scouring processes.

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TALK

Successes and Lessons Learned from 5 Years of Monitoring Riverbank Bioengineering Projects in Calgary

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Under The City of Calgary's Riparian Action Program, The City embarked on a five-year (2018-2022) Riparian Monitoring Program (RMP) with an objective of monitoring the effectiveness of riverbank bioengineering works completed in the city over the last decades. Both the structural and vegetation components were assessed in detail on almost 70 bioengineering sites along major rivers and creeks in Calgary, many of which were constructed after the 2013 flood. Detailed vegetation survival and growth data were collected by technique for almost 11,000 potted plants and live cuttings.

This presentation will share the top 5 results from the RMP including:

- Results for the assessment of design, implementation and maintenance practice effectiveness to support improvement in overall bioengineering project delivery;
- Confirmation of best practices such as deep planting, and recommended planting schedules;
- Comparison of measured woody vegetation survival and cover for several bioengineering technique against targets values from the literature;
- Results for the top performing species and stock types; and,
- How the RMP helps to fill a data gap for post-construction monitoring methods, data, analysis and results.

Because there is a unanimous technical and scientific observation that there is a gap in the understanding of the performance of bioengineering projects, the RMP results provide an important contribution to the body of literature for bioengineering works in a semi-arid/prairie environment.

KEYNOTE SPEECH

Desempeño del geocompuesto de fibras naturales como tecnología sustentable en Brasil.

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Las técnicas de bioingeniería de suelos se definen como la asociación de materiales inertes y materiales vivos, como las plantas, para la recuperación de áreas degradadas, ya sea en laderas o riberas, y se distinguen por ser ambientalmente sostenibles, eficientes y de menor costo que la ingeniería tradicional. Entre los materiales comúnmente utilizados en trabajos de bioingeniería de suelos, destaca el uso de geotextiles, que pueden estar hechos de fibras sintéticas, fibras naturales o mixtas. Los beneficios de los geotextiles se relacionan con la separación de materiales, el refuerzo del suelo, la filtración y el drenaje, así como la protección y mayor durabilidad de las estructuras. Los geotextiles de fibras naturales son bastante resistentes y biodegradables, y vienen en varios tipos como geomallas, geocompuestos, geoceldas y geotubos. Esta ponencia tiene como objetivo presentar el trabajo desarrollado con la producción, análisis y uso de geotextiles hechos de fibras naturales provenientes de especies de clima tropical.

Performance of different geotextiles manufactured from tropical species fibers on soil erosion control

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Soil bioengineering techniques are defined as the combination of inert and living materials, such as plants, for the restoration of degraded areas, whether on slopes or riverbanks. They are distinguished by their environmental sustainability, efficiency, and lower cost than traditional engineering. Among the materials commonly used in soil bioengineering projects, geotextiles stand out. These can be made of synthetic, natural, or mixed fibers. The benefits of geotextiles relate to material separation, soil reinforcement, filtration and drainage, as well as the protection and increased durability of structures. Natural fiber geotextiles are quite durable and biodegradable and come in various types, including geogrids, geocomposites, geocells, and geotubes. This presentation aims to present the work developed in the production, analysis, and use of geotextiles made from natural fibers from tropical climate species.

TALK

Performance of geocomposite of natural fibers as sustainable technology in Brazil

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The objective of this work was to evaluate the geotechnical efficiency of a multilayer geocomposite geotextile, manufactured from natural fibers of *Thypha domingensis* Pers, *Agave sisalana* Perrine, *Ananas comosus* (l.) Merril, *Musa* spp. and *Boehmeria nivea* (L.) Gaud. for erosion control on slopes. The production process includes decortication, drying and molding the fibers into three-dimensional structures in order to promote soil stability in vulnerable areas to degradation. The geocomposites were produced using braiding and pressing techniques (geogrid and drainage core), using chemical treatments that improve the mechanical strength and durability of the natural fibers (Figures 1abc).

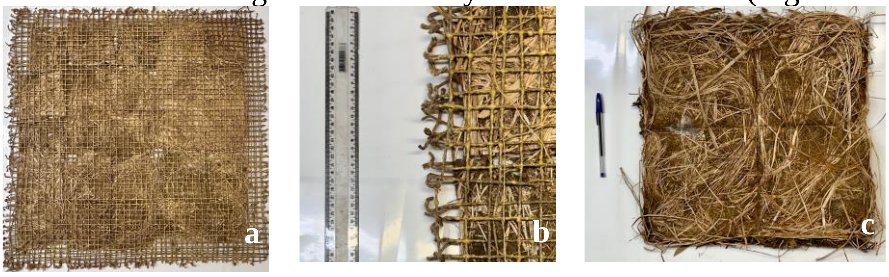

Figure 1.a-Geocomposite (geogrid and drainage core), b-Geogrid detail, c-Drainage core).

A prolonged saturation analysis was carried out, in which the material was subjected to a saturation and drying regime at six different times, allowing the evaluation of the influence of the saturation duration on the water absorption capacity of the drainage core. Aqueous extracts from hydrorretentive cores were tested in bioassays using arugula (*Eruca sativa*) seeds. Physiological performance was quantified via ANOVA and Tukey's post hoc test ($\alpha = 0.05$), analyzing mean shoot length and mean root length. Complete formulations (N1: fibers + resin + D-limonene) promoted a 106.8% increase in shoot length compared to the control (15.12 mm - 31.28 mm; $p < 0.001$), while no treatment significantly altered root development ($p = 0.104$; $\eta^2 = 0.061$), indicating a preferential effect on foliar biomass.

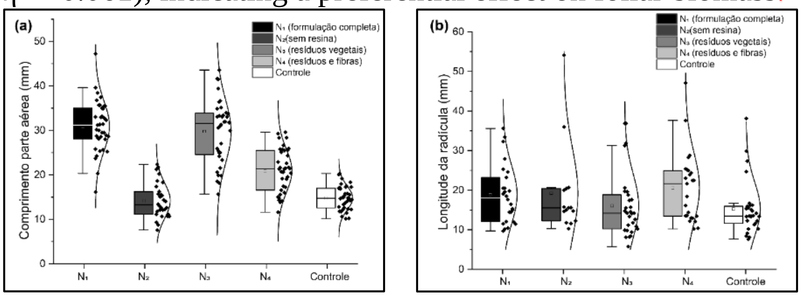

Figure 2. (a) Average length of the shoot and (b) average length of rocket roots extended in extracts of different water-retaining cores made from *Typha domingensis*

The geocomposites demonstrated a high-water retention capacity, absorbing over 200% of their weight in water within 48 hours, and showed no phytotoxicity, with germination rates exceeding 90% across all extracts and N1 reaching 98% (Δ +5.4% vs. control; $p < 0.001$). Additionally, the synergy between fibers and resin promoted selective bioestimulation, accelerating mean germination time to 2.045 days. The developed geocomposite integrates mechanical slope stabilization with bioestimulant properties, facilitating the fast establishment of vegetation in degraded soils, positioning itself as a multifunctional strategy that enhances seed germination and foliar development without compromising environmental safety. The water-retaining core composed of *T. domingensis* fibers and natural additives, has a water absorption coefficient (172% ± 10%) that is higher than the coefficient presented by other common natural fibers, such as: Stipa fiber, linen, hemp, sisal, jute and coconut.

TALK

Three-dimensional modelling of root-soil composite with fractal roots using homogenization theory

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Serious soil erosion and shallow landslides strongly affect industrial and agricultural production, and pose a serious threat to people’s safety. Traditional engineering measures for slope protection are costly and hinder the natural restoration of the ecological environment. The effectiveness of plant roots in soil reinforcement and landslide protection is undeniable, offering an economic and ecological approach to safeguarding slopes and human activities (Fig.1a). Although researchers acknowledge the importance of ecological measures in forestry for mitigating natural disasters, the mechanics and behavior of rooted soils in complex natural environments remain insufficiently understood. This research focuses on investigating the mechanical properties of rooted soils with fractal roots and developing rigorous, accurate evaluation methods. A three-dimensional model of the root-soil composite, initiated with a non-uniform root distribution of roots based on homogenization theory, has been proposed. The equivalent elastic modulus and strength parameters of the composite are then calculated via a root-soil unit cell (UC) (Figs.1b~d). In this study, root-soil composites are treated as natural fiber-reinforced composites to better capture the reinforcement effect of randomly and fractal-distributed roots in nature. This approach reveals the impact of complex root distributions on the mechanical properties of root-soil composites and clarifies the mechanism of root reinforcement. The accuracy of the composite calculation method has been validated through geotechnical tests, such as direct shear and triaxial tests. The results showed that the UC model of the root-soil composite could effectively predict its equivalent elastic parameters. A parametric analysis using the proposed homogenization model shows that roots can mobilize significant soil portions to resist deformation by increasing both the stages and complexity of root distribution. The presence of plant roots significantly enhanced the shear strength of the root-soil composite, primarily due to an increase in cohesion. New methods, technologies, and materials that enhance the ability to predict and evaluate slope failure mechanisms were discussed and forecasted. This paper presents a new perspective on developing a constitutive model for root-soil composites, highlighting its potential value for engineering applications that use roots as reinforcement.

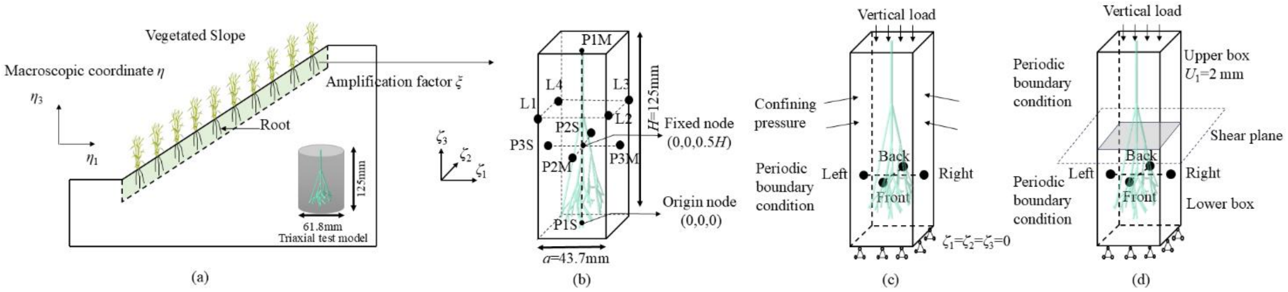

Fig.1 Schematic diagram of root distribution and UC. (a) Vegetated slope with macro coordinates, (b) three dimensional root-soil UC with mesoscale coordinates for elastic modulus calculation, (c) triaxial simulation model of UC, (d) shear strength calculation model of UC.

TALK

Comparative analyses of hydrological and mechanical reinforcement by *Salix alba* L. and native vegetation in canal bank stabilization

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Vegetation-integrated solutions, combining inert materials with plants, offer sustainable approaches for stabilizing canal and stream banks. While prior research has extensively evaluated the mechanical and hydrological reinforcement provided by individual plant species, real-world scenarios often involve mixed vegetation communities. This study addresses this gap by investigating the combined effects of *Salix alba* L. (white willow)—a dominant species along Dutch canals and water bodies—and naturally co-occurring vegetation.
Field measurements were conducted over 17 months along three canal embankment sections:

1. *Salix alba* L. with native vegetation (combined plot),
2. Native vegetation alone (natural plot),
3. *Salix alba* L. alone (willow plot).

Hydrological parameters (soil suction and water content) were monitored at three profiles (25 cm to 3 m from the canal edge) on the combined and natural plots, while mechanical reinforcement (root density, shear strength) was assessed once during the study period. All vegetated plots demonstrated significantly higher mechanical shear strength than bare soil, though no marked differences were observed among the vegetated sections (combined, natural, and willow plots). The combined plot exhibited the highest root length density, while root volume was smallest in the natural plot. Deeper soil layers (below 50 cm) in the combined plot induced higher suction than the natural plot, while surficial layers showed no significant differences between the two plots. All suction values remained below 6 kPa, likely due to the study coinciding with the wettest recorded period in the region.
These results highlight that during prolonged wet conditions—a worst-case scenario—where hydrological benefits may be limited, mechanical root reinforcement becomes critical for stability. While the introduction of a new species is often sought for stabilization, engineers need to evaluate whether natural vegetation alone can provide sufficient reinforcement. This study underscores the need to evaluate vegetation performance under real-world, mixed-growth conditions to optimize eco-engineering strategies.

TALK

Willows root distribution on riverbanks: first hints from field measurements to model calibration for soil and water bioengineering design.

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Extensive to measure, tree root distribution in riparian soils is essential to estimate the spatial and temporal repartition of soil reinforcement. Soil and water bioengineering techniques implemented for riverbank stabilization are mainly made of willows, pioneer species highly represented in riparian environments and also studied, particularly in the form of transplanted cuttings (Pasquale et al., 2012; 2014) or as representative of logs (Bau et al., 2020). Being able to model root distribution and thus root mechanical effects on soil reinforcement is key for practitioners to design or adjust riverbanks layout.
Hydraulic erosion is the main process leading to the destabilization of riverbanks with soil bioengineering structures (Leblois et al., 2022; 2024). Understanding the willows root distribution in riparian environment will help to better estimate bank erosion hazard under specified hydraulic constraints. In turn, this will also allow for optimizing the design of soil bioengineering structures and to model the dynamics of bank stability while taking the temporal development of vegetation into account (e.g., similarly to what is implemented in the model BankforNET, https://bankfornet.cosci-llc.com/).
Differently from previous studies, which mainly focused on cuttings (e.g., Pasquale et al., 2012; 2014), this work analyses more than 2000 willow root measurements taken from 11 sectors at two riverbanks sites. The study first describes the statistics of roots distribution (laterally and vertically) with the respective contribution of the different roots diameters. This data set is then used to calibrate the root distribution model proposed by Perona et al. (2022). Finally, as roots are known to contribute to increase the critical shear stress of riverbanks, thereby reducing the erosion hazard, a rough estimation of this mechanical reinforcement is proposed for the cases of the field measurements.
This study aims to raise practitioners' awareness regarding the distribution of willow roots in riparian soils and their potential role in bank soil reinforcement with operational applications.

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POSTER

The Effects of Arbuscular Mycorrhizal Fungi on Grass Establishment and Aggregate Stability in Compacted Soil

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Arbuscular mycorrhizal (AM) fungi play a vital role in plant stress relief and soil aggregate formation, which are crucial for improving ecological restoration on slopes. This study aims at enhancing the understanding of the interactions between AM fungi and grass species in compacted soil and their effects aggregate stabilisation. In a pot-culture experiment (Fig. 1), vetiver (*Chrysopogon zizanioides*) and Bermuda grass (Cynodon dactylon) were planted in compacted decomposed granitic soil, with and without inoculation of arbuscular mycorrhizal (AM) fungi. Additional treatments included Bermuda grass, inoculated or not, in uncompacted loose soil, resulting in a total of six treatments. In each pot, the root zone and hyphae zone were separated using a mid 38- m mesh. After twenty weeks, plant biomass and root traits, AM fungal colonization and hyphae length density, soil organic matter, and aggregate stability were determined.

Our findings demonstrate that AM fungi significantly improved overall growth of vetiver grass in compacted soil and Bermuda grass in loose soil (Fig. 2). While Bermuda grass root development was reduced in compacted soil compared to loose soil, aboveground growth remained unaffected due to the support of hyphal network. This indicates the potential of AM fungi in promoting ecological restoration efforts on slopes. The influence of these changes on soil aggregate stability will be discussed during the conference.

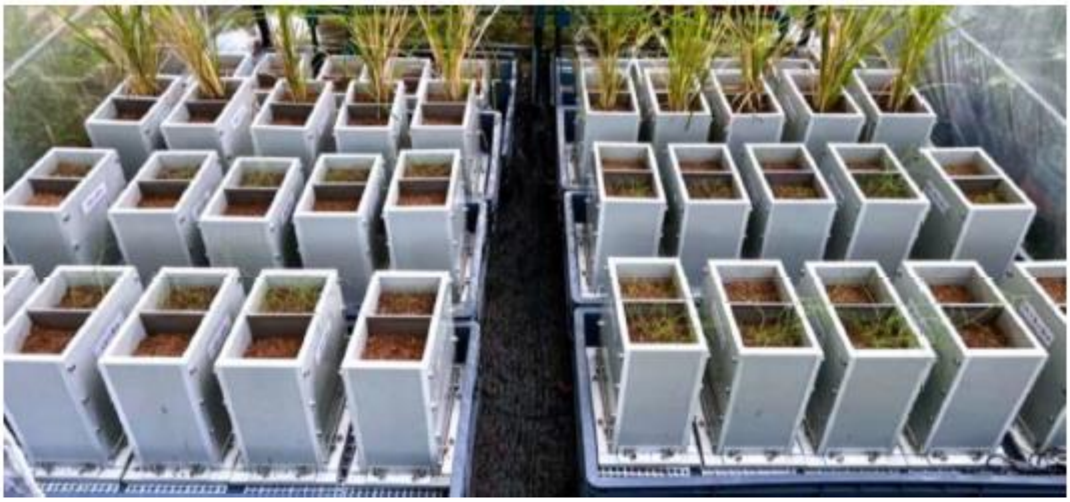

Fig 1. Experiment setup

ROUND TABLE

Can we trust root tensile trait data? A global initiative for testing reproducibility

Convener: Zhun Mao (INRAE, France), Kenneth Loades (JHI, UK) and David Boldrin (JHI, UK)

Root mechanical traits, such as tensile strength and modulus of elasticity, are known to show high variability at intra- and interspecific levels, especially for very fine roots. Unravelling the mystery of this high variability has become a major research and development challenge for biologists, ecologists and eco-engineers. Very likely, one of the most important sources of this variability is the experimental procedure, since the test protocol in terms of root preparation, apparatus, initial sample length, clamping, test speed, failure assessment and trait calculations varies from study to study and is far from being standardised. Little is known about how this wide variation in methodology affects estimates of root mechanical traits.

The SBEE 2025 conference provides us with a valuable opportunity to propose an initiative to the world's experts in plant mechanics: to work together to test the reproducibility of root mechanical trait values using a participatory approach. To do this, we plan to send the same and traceable root materials to any researcher or research group willing to measure root mechanics in their own way using their own equipment. The results and supporting data will then be collated to compare the variation in results and identify the underlying factors. The final diagnoses are expected to be valorised as scientific publications with all participants as co-authors and presented at the next SBEE conference.

Such an initiative, based on a participatory approach, will not only contribute to the standardisation of the test protocol for root mechanics, but will also promote cooperation and cohesion among international experts.

Key words: root mechanical traits, reproducibility, test protocol, participatory approach

TALK

pyrootmemo: unifying root reinforcement models

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Predicting the reinforcing effect of plant roots on slope stability has been of academic and professional interest for over half a century. A large number of analytical, empirical, semi-empirical and numerical models have since been proposed. As a physics-based model using well-established constitutive laws or widely used numerical techniques is still largely lacking, many researchers and practitioners continue to employ multiple methods from the literature. However, because these models use a wide variety of soil and root parameters, assumptions, coefficients, systems of measurement units as well as calculation algorithms, it can be challenging to compare results.

We present an application, “pyrootmemo”, to simplify the use and comparison of models. Currently incorporated models include well-known models based on force-equilibrium such as those by Wu and Waldron, as well as recent extensions of fibre bundle models and root bundle models. pyrootmemo was developed entirely in Python, utilising the principles of object-oriented programming. Controlled terminology, representing models as objects, and standardisation of data structures enable smooth and error-free model simulations and comparisons. Furthermore, automated metadata extraction yields reproducible model calculations, thus ensuring transparency when making design decisions.

Pyrootmemo is ongoing project that is open-source and free to use. The application is modular, enabling users to adapt and implement elements of pyrootmemo within their own models and code. We highly welcome new contributors and contributions. Our aim is to promote accessibility, interoperability, (re)usability, transparency and standardisation, thus facilitating applications of model-based assessments and design of nature-based solutions against climate-driven geohazards.

TALK

Vegetali Project: Developing and promoting soil and water bioengineering on Reunion Island

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Soil and water bioengineering (SWBE) is based on the observation and imitation of natural models in response to land-use planning issues. It is a set of construction techniques in which plants, alone or combined with inert materials, play a structural role in addition to their landscaping aspect.
On Reunion Island, these techniques for riverbanks are still poorly understood, and are rarely, if ever, integrated into river and gully development projects.
The VEGETALi project, led by the ARBRE association in collaboration with INRAE Grenoble, aims to remove the barriers to the use of living plants to help preventing riverbank erosion, and also to provide managers with concrete tools enabling them to implement operational SWBE techniques to protect property and people while preserving biodiversity.
The project brings together technical and financial partners, research organizations and local authorities responsible for aquatic environment management, to meet the objectives of improving the state of aquatic environments.
The first phase of the project (currently underway) aims to describe riparian habitats. To this end, botanical surveys of riparian zones and hydromorphological surveys have been carried out at 60 stations. The results will provide a current picture of riparian habitats, but also to identify functional natural models to be copied in future SWBE techniques.
In addition, these observations will enable us to select plants (herbaceous, shrubby, arborous) with interesting characteristics for SWBE (developed root system, flexibility of branches, capacity for multiplication and regeneration). These characteristics will guide the use of these species in different SWBE techniques.

During the second phase of the project, tests will be carried out in nurseries (cuttings, brush layers, fascines, etc.) and current knowledge will be completed (root system, vegetative propagation, breaking dormancy in certain species).

Ultimately, the project aims to develop a SWBE sector in La Réunion island.

TALK

A case history of coastal erosion protection using nature-based solutions in the Outer Hebrides

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Global climate change effects demonstrated as change in sea levels, the severity and duration of storm events, as well as changes in temperature, have brought changes in the volume and location of massive soil losses. These effects are more visible and devastating on small islands like the ones in the Scottish Outer Hebrides where there are limited resources and capacity to integrate mitigation and protection measures against coastal erosion despite the history of occurrence of the problem. In this case history, we introduce the timeline of events and actions related to the erosive processes shaping the west-facing bay on the island of Vatersay. Through a critical review of documented events and actions, we will present the level of existing knowledge within the communities on the island and chart the capacity for future change in terms of application of nature-based solutions (NBS) for mitigation of and protection from coastal erosion. Additionally, we will demonstrate a range of novel methods which can be applied to record, monitor, and plan future mitigation and protection measures. The use of laser 3D scanning and design, as well as open-source beach monitoring platforms will be detailed in context of potential design with vegetation for protection of the vulnerable dune systems on Vatersay. The results of this study will showcase the past and current efforts of the communities which can be replicated and up-scaled in similar geo-climatic conditions globally. Soil- and water-bioengineers will benefit from the tacit knowledge within the affected communities while the novel application of NBS will be of benefit for the communities which will be empowered to improve social cohesion and resilience.

TALK

An overview of Soil and Water Bioengineering as Nature Based Solution for erosion control in the tropics

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Soil and water bioengineering (SWBE), the most frequently mentioned Nature Based Solution for landslide protection and erosion control, represent an alternative or a complement to reinforcement structures from civil engineering. These approaches have been the subject of considerable literature, particularly in temperate environments, but have received less attention in tropics, despite frequent occurrences end heavy consequences of soil erosion and landslides. A review on SWBE experiments and suitable species is still needed.

A literature review was conducted on more than 800 references. We selected 51 references that reported effective SWBE projects. We extracted from each reference 14 variables related to the context, the technical aims, the structures implemented and their monitoring. We also completed a species list of tropical species used or recommended for SWBE, precising their taxonomy, their growth form, their way of propagation, their native distribution, and if they were native from the place where they were implemented.

The results mapped heterogeneous efforts, with Africa and Oceania particularly neglected. In America and Asia, a large diversity of SWBE techniques (n=28) were successfully implemented. However, monitoring was only conducted on short period and without standardized evaluation methods. On the 466 species mentioned in worldwide tropics, only 25% have been tested *in situ*, mostly out of their native range, with a limited plant diversity on each work. SWBE displays a promising potential for tropics, but there is still a striking lack of knowledge about the identification, the development, and the biotechnical performance of suitable tropical species. Investigations including well defined, long term and standardized monitoring methods are needed to assist practitioners and to facilitate SWBE transferability in tropics.

TALK

A fundamental tool for reducing the risk of landslide disasters in Veracruz is the Inventory (1970-2024).

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The state of Veracruz is exposed to various geological phenomena; however, the one that poses the greatest threat is landslides due to severe damage and economic and human losses, which have already occurred. To implement effective risk reduction, strategies and an adequate assessment of the danger posed by landslides is necessary. For this, it is essential to prepare an inventory, which identifies and classifies the typology of movements, their location, date of occurrence, extension, size, damage to vital and strategic services, as well as human and economic losses and trigger events (Alcantara and Murillo, 2008; McCalpin, 1984; Guzzetti, et al., 2012). The present study compiles information from various sources such as: National dataset on susceptibility of the phenomenon of mass movement 2012-2022 (INEGI, 2025); Risk Atlas of the State of Veracruz, (SPC, 2024); Landslides triggered by meteors in 2013. "Case studies" (Morales-Barrera, and Rodríguez-Elizarrarás, 2014), DESINVENTAR Disaster Inventory System (OSSO, C., 2025); and Most frequent geological hazards in the state of Veracruz, (Rodríguez-Elizarrarás and Morales-Barrera, 2014).

These databases collect information using very different methodologies, which is why they complement each other; therefore, it was necessary to process and standardize the information. In the resulting catalog, generally the term "landslide" is applied to represent all events, although in some cases the type of movement is differentiated. Furthermore, it includes data on the location in geographic coordinates, year and month of occurrence, source of information, lithology, type of soil and vegetation, edaphology, and in some cases characteristics of the landslide, details of the damage and losses, and trigger event.

The catalogue that we present provides an account of the events that occurred between 1970 and 2024, recording a total of 6,519 landslides; however, the annual spatio-temporal distribution could only be obtained from 2003 to 2024. This analysis highlights that the majority of landslides occur between July and November, a period that coincides with the rainy and tropical cyclone season in the Atlantic. Unfortunately, the records do not determine the magnitude of the event.

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TALK

Barriers and drivers to Soil and Water Bioengineering in Quebec

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The implementation and success of Nature Based Solutions in general, and Soil and Water bioengineering (SWBE) in particular, depend on technical, biological but also social and cultural factors. The FLAG project (*Barries and Drivers to Soil and Water Bioengineering*) aims to first recognize the obstacles to its use in Quebec (Canada), as well as the possible drivers to overcome them, adopting a social geography approach.

We conducted a documentary analysis of two achieved and one planned SWBE projects for shoreline stabilization, and we conducted semi-structured interviews with 35 people involved in the design, planning, construction, maintenance and regulation of these projects.

Our results show that the organization of hydrosocial territory, and more precisely the lack of consideration from practitioners about the river connectivity, complicates the implementation of SWBE.

- **Longitudinal connectivity:** Riparian land often belongs to small private owners. In some cases, the private interests and the absence of collective dynamics makes it difficult to carry out coherent projects that take longitudinal connectivity into account.
- **Lateral connectivity**: While the SWBE structures are supposed to improve lateral connectivity because of the presence of plants from the top to the bottom of the shoreline, some engineer practices and regulation on encroachment often limits the ambition of projects, leading to inappropriate achievements (vegetation planted too high, riprap at the bottom of the bank, vertical structures etc.).
- **Landscape connectivity:** In all the projects we analysed, designers tried to include elements to restore landscape connectivity (restoration of habitat functions, infrastructures to restore natural sediment dynamics). Yet in practice, these attempts revealed to intervene against social demand focusing on the shoreline stabilization, in a localised and short-term perspective.

Drivers are identified for each barrier, and we highlight the role of community of practice to activate these drivers. Our work contributes to the literature on SWBE and Nature-Base Solutions implementation, as well as literature on hydrosocial territory. It also reveals the importance of interdisciplinary approaches, particularly around some border concept such as connectivity.

KEYNOTE SPEECH

Efectos del fuego en las interacciones vegetación-suelo e implicaciones para deslizamientos de tierra: estudios en el sureste de Brasil.

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La acción histórica y actual del fuego en el bioma original del Bosque Atlántico há culminado en su fragmentación y reemplazo progresivo por vegetación herbácea-arbustiva, cada vez más rápida, ante los incendios inducidos por el aumento progresivo de días secos en los últimos 50 años y por la inducción humana, como se observa en la región montañosa de Río de Janeiro, SE-Brasil. En enero de 2011, el municipio de Nova Friburgo se vio afectado localmente por varios miles de deslizamientos de tierra, la mayoría (80%) de los cuales fueron traslacionales superficiales (con superficie de deslizamiento ~1 - 2 m/profundidad). La investigación de campo en una cuenca de drenaje fuertemente afectada por 382 de este tipo de deslizamientos de tierra, en pendientes pronunciadas (30-40^{0}), mostró que el 74% estaba cubierto por vegetación herbácea-arbustiva, que cubre solo el 24% del área total de la cuenca. En vista de este hecho, se instalaron dos estaciones experimentales para estudios detallados de las interacciones fuego-biota-suelo-agua e implicaciones para la detonación de deslizamientos traslacionales superficiales: 1) Estación Campo do Coelho (desde enero de 2015), incluye caracterización geobiofísica (suelo y vegetación), monitoreo continuo de precipitaciones y succión en el perfil del suelo, incluyendo una ladera cóncava-convergente (32^{0}) con vegetación herbácea-arbustiva quemada en diciembre de 2014 y septiembre de 2019 y otra ladera similar, adyacente, cubierta por bosque secundario degradado de 25-30 años, con uso agrícola previo del tipo de roza y quema ; 2) Estación Boa Vista (desde 2022), para estudios experimentales de los efectos del fuego controlado sobre las propiedades del suelo, en el borde de bosque degradado con uso previo de agricultura de roza y quema y en vegetación herbácea con uso previo de pasto e fuego recurrente. Los resultados se discutirán en esta conferencia, destacando los efectos del fuego sobre las propiedades del suelo y las implicaciones para la detonación de deslizamientos traslacionales superficiales.

Effects of fire on vegetation-soil interactions and implications for landslides: field studies in SE-Brazil

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The historical and current action of fire in the original Atlantic Forest biome has culminated in its fragmentation and progressive replacement by herbaceous-shrub vegetation, increasingly rapid, in the face of fires induced by the progressive increase in dry days in the last 50 years and by human induction, as observed in the mountainous region of Rio de Janeiro, SE-Brazil. In January 2011, the municipality of Nova Friburgo was locally affected by several thousand landslides, the majority (80%) of which were shallow translational (w/slip surface ~1 - 2 m/deep). Field research in a drainage basin (54 km^2) heavily affected by 382 of this type of landslide, on steep slopes (30-40°), revealed that 74% of the landslides were covered by herbaceous-shrub vegetation, which accounts for only 24% of the basin's total area. In view of this fact, two experimental stations were installed for detailed studies of fire-biota-soil-water interactions and implications for the detonation of shallow translational landslides: 1) Campo do Coelho Station (since January 2015), includes two monitoring sites for geo-biophysical characterization (soil and vegetation) and continuous monitoring of rainfall and soil suction: one site is located in a concave-convergent slope (32°) with herbaceous-shrub vegetation burned in December 2014 and September 2019; another site is an adjacent slope, covered by degraded secondary forest of 25-30 years, with previous agricultural use of the Slash & Burn type; 2) Boa Vista Station was installed in January 2022 for experimental studies on the effects of controlled fire on soil properties, including two monitoring sites: one at the edge of a degraded secondary rainforest (40 years) with previous use of Slash & Burn agriculture and, also, in herbaceous vegetation with previous use of pasture and recurrent fire. The results will be discussed in this lecture, highlighting the effects of fire on soil properties and implications for the detonation of shallow translational landslides.

KEYNOTE SPEECH

Learning from (slope) failure: is vegetation the key to success for soil & water bioengineering interventions?

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Soil & water bioengineering (SWBE) techniques have been employed extensively to manage landslide and erosion hazards worldwide. SWBE techniques combine well-established ground and ecological engineering principles to deliver a wide array of engineering and environmental functions. These functions are effectively provided by embedding live vegetation in the SWBE interventions. However, monitoring of built SWBE interventions seldom occurs, resulting in important knowledge gaps related to their performance. In addition, reports on SWBE failure are rare, hindering useful learning lessons to achieve best practice.

This research focuses on the failure of a SWBE intervention built to reinforce and stabilise an active coastal slope in Northeast Scotland in June 2022. The intervention comprised multiple SWBE techniques – i.e., double live cribwall, live slope grating, branch mattress, and live pole drain, and it was equipped with a telemetric monitoring station collecting soil-water records over time. Following severe and cold weather conditions, and prior to vegetation establishment, the intervention slipped down to the North Sea in December 2022 (Fig. 1). The aim of this research is to assess whether vegetation could have prevented failure had it been established in the intervention. The research comprises four parts: (i) Description of SWBE intervention implementation approach; (ii) Analysis of the hydro-mechanical factors that likely triggered failure; (iii) Model-based, stability assessment under different vegetation development scenarios; and (iv) Lessons learnt and way forward. The results will provide novel insights into SWBE techniques implementation, monitoring, and modelling, and it will open exciting discussion on future research and best practice in soil & water bioengineering.

Figure 1. SWBE intervention after failure. Credit: John Howell.

TALK

Meta-Analysis of Wooden Element Degradation in Live Crib Walls for Soil and Water Bioengineering Applications

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Soil and Water Bio-engineering (SWBE) is a technique of soil restoration that utilizes native plants as construction materials. These can be used alone or with traditional or innovative inert materials. The primary goal of SWBE is to restore ecosystems degraded by natural or human activities while promoting the natural dynamics of vegetation and geomorphological processes to conserve and enhance biodiversity. One popular technique employed in SWBE is the creation of live crib walls. This method combines wooden structural elements with living vegetation to stabilize slopes and riverbanks.
This study conducts a meta-analysis of existing research and case studies on live crib walls to assess the factors that influence the degradation of wooden elements. These factors include wood species, environmental conditions, and construction techniques.
Understanding the durability of structural wood, the growth of tree specimens, and the plant community's evolution is essential for long-term functionality prediction of live crib walls since wood is a key component of these structures and phytocenosis affirmation. However, the durability of wooden elements is not uniform throughout the structure. Critical areas, such as joints, buried sections, and regions exposed to humidity, are more susceptible to degradation. Traditional methods for evaluating the condition of wood, such as direct mechanical tests in the laboratory after dismantling live crib walls, can be expensive and counterproductive for soil restoration, often compromising the structural integrity during the process. A common on-site investigation of the residual goodness of material is the use of a dendrodensimeter (Resistograph®), a diagnostic drill that measures the resistance of wood to penetration. This tool provides valuable insights into the internal condition of the wood without causing damage.
The research aims to provide practical and technical recommendations that optimize these structures' design and initial construction. By focusing on sustainable material selection, precise placement, and the integration of diagnostic tools for periodic monitoring, this study aims to enhance the longevity and effectiveness of live crib walls.

TALK

Restoration of Vulnerable Nepalese Mountain Landscapes through adoption of Bio and Eco engineering measures

Bishnu Hari Poudyal
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Restoration of Vulnerable Nepalese Mountain Landscapes through adoption of Bio and Eco engineering measures Bioengineering and ecological engineering are considered highly relevant to make the fragile landscape and its community resilient to climatic, socio-economic and political changes. Such initiatives are successfully implemented in Churia region of Nepal, one of the most vulnerable terrestrial landscapes in South Asia. Despite being a lifeline and the source of water recharge for the downstream communities settling around Bhabar and Terai, the unplanned and scattered conservation initiatives from various agencies were futile. Diverse issues and their drivers including increased soil erosion, landslides and gully formation, flash floods and river cutting, deforestation and forest degradation, loss of agricultural productivity, increased fire incidences and invasive species in the forests, have contributed to make Churia region further degraded and vulnerable. Among number of efforts made by the Government and non-government agencies to restore the region, Building a Resilient Churia Region in Nepal (BRCRN) project is implementing landscape restoration interventions adopting bioengineering and ecoengineering methods after formulating a river systems specific plans i.e. Critical Ecosystem Restoration Plans (CERPs). Such plans are being implemented using ecological and engineering tools and techniques and applying bioengineering techniques securing fruitful engagement of the diverse stakeholders at multiple level to integrate human society with its natural environment. Construction of conservation ponds/ rainwater harvesting ponds maintaining the ecological functionality and human wellbeing through ecosystem-based approach and construction of river bank protection embankments with the well mix of vegetative and civil engineering works has successfully supported irrigation water supply and ground water recharge for the communities and rehabilitated hundreds of hectares of sand deposited agricultural fields respectively. The positive impacts of those activities on improving ecological functionality around the river ecosystems and strengthening agri-food systems of Bhabar and Terai regions of Nepal has indicated the effectiveness of such interventions for making Churia landscape and its communities more résilient.

TALK

Impact of Wildfires on Soil Erosion in Mediterranian Pine Forest: RUSLE Model and GIS-Based Analysis Assessment

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Soil erosion is a critical environmental issue, particularly in forested areas where vegetation plays a vital role in slope stability. This study aims to assess soil erosion dynamics in a pine forest area before and after a wildfire event, using the Revised Universal Soil Loss Equation (RUSLE) model combined with Geographic Information Systems (GIS) software, specifically QGIS (version 3.34.14), for spatial analysis. The RUSLE model, an updated version of the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978), was applied to estimate soil loss by calculating the key factors influencing erosion: rainfall erosivity, soil erodibility, slope length and steepness, land cover, and conservation practices (Renard et al., 1997). These factors were derived from pre-existing databases and processed exclusively through QGIS. Rainfall erosivity (R) was estimated using regional climatic data, soil erodibility (K) was calculated from soil maps, and the topographic factor (LS) was derived from Digital Elevation Models (DEM). The cover-management factor (C) was determined based on Panagos et al. (2015), while conservation practices (P) were assigned default values due to the lack of local data. The study was conducted in the Pineta di Castel Fusano, a Roman pine forest located in the municipality of Rome, Italy. The region’s vulnerability highlights the need for effective forest management strategies (Cutini et al., 2009). Geoprocessing tools within QGIS were used to process satellite data to assess vegetation cover before and after the wildfire, allowing for a detailed comparative analysis of erosion rates. The modified RUSLE model was then used to determine the maximum allowable soil erosion rate, following the methodology described by Verheijen et al. (2009), which defines thresholds for tolerable erosion at the European scale, and incorporating the principles of Soil Loss Tolerance (Skidmore, 1982). This study highlights the significant impact of wildfires on soil erosion, particularly in Mediterranean ecosystems, which are increasingly threatened by climate change and anthropogenic pressures. Effective land management strategies, including the introduction of appropriate vegetation cover, are essential for maintaining soil stability and reducing post-fire erosion risks. The application of QGIS, in combination with the modified RUSLE model, provides valuable insights for post-fire erosion assessment and offers a scalable approach for the conservation of vulnerable Mediterranean ecosystems.

TALK

Spatial-temporal evolution of the root system architecture of vetiver grass – An attempt to quantify the dynamic root growth in three-dimensional space

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Roots provide additional cohesion to increase the stability of the vegetated slopes in shallow depths. Root system architecture (RSA) and root mechanical traits are the major factors contributing to this additional root cohesion, in which the former is considered to contribute more than the latter. Despite its significance, understanding of the RSA and its evolution with time and space is limited due to its complex distribution in space, susceptibility of its evolution to many external factors and limitations in the existing quantification methods. Due to this lack of knowledge, idealized RSAs are generally used in the analysis of vegetated slope stability which can either underestimate or overestimate the effect of vegetation on the stability of the slope. This study aims to quantify the RSA of vetiver grass, its evolution through the three-dimensional space and the effects of external factors like the availability of excess nutrients (application of fertilizers), competition among plants, and the presence of light on the evolution of the RSA during the early establishment period of the plant. An advanced non-invasive technique, X-ray computed tomography (CT) has been used to capture the RSA. Vegetated samples prepared with vetiver grass were scanned at regular time intervals during their growing period. The samples were subjected to different treatments to simulate the aforementioned external factors. Based on the reconstructed three-dimensional root images extracted from the CT scans, algorithms have been developed to characterize the root parameters. Moreover, based on experimental data and the parameters developed, three-dimensional root growth models will be developed for the vetiver grass which are capable of predicting RSA at a given growth stage thereby providing valuable data necessary for the vegetated slope stability analyses.

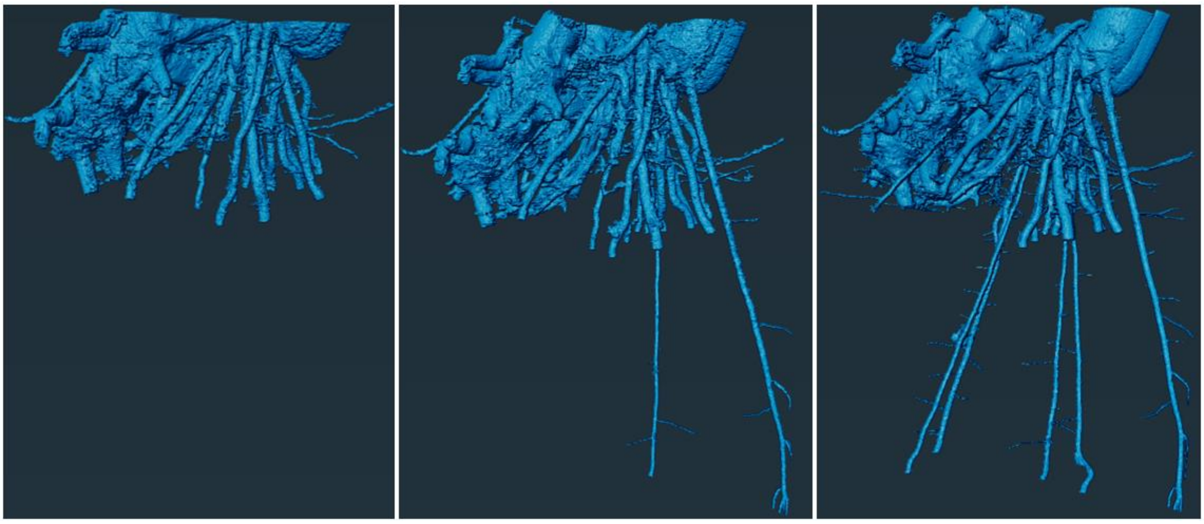


Fig 2: Reconstructed images of the root of a vegetated sample showing the growth of the root through the 3-D space at different stages of the growing period

TALK

The Adaptability of Live Grating Structures for Applications in Slope Stability, Stream Bank Protection, and Habitat Enhancements in Canada.

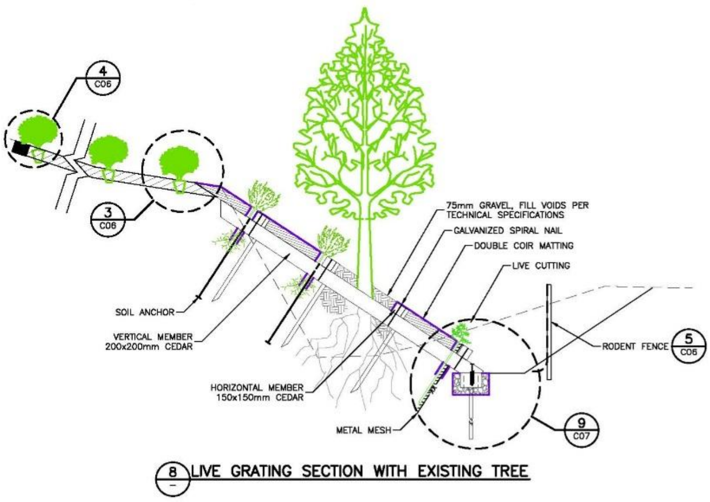
P. Raymond
Terra Erosion Control Ltd, 308 Hart Street, Nelson, British Columbia, Canada

Eroded steep slopes and stream banks can be challenging to stabilize using nature-based solutions such as soil and water bioengineering, especially when sites have steep gradients, are partially vegetated with mature trees, or are adjacent to existing infrastructure.

Live grating application, or slope grid, is a mixed technique involving timber, rocks, and biodegradable geotextile combined with native vegetation and soil amendments to vegetate and stabilize very steep slopes and riverbanks with gradients up to 55 degrees.

The benefits and advantages of using live grating applications include

a. Limit deep excavation into a slope
b. Reduce damages to existing tree root systems
c. Conserve existing vegetation
d. Limit the footprint on riverbanks and slope benches
e. Provide large woody debris component that assists in retaining soil moisture and enhances soil microorganism activity.
f. Provide nature-based solutions combined with civil engineering practice to protect the riverbanks and slopes.



Drawings: Urban System and Terra Erosion Control Ltd.

Examples of designed, implemented, and monitored live grating applications for residential, urban, and rural areas will be presented. These applications were used to stabilize sites with ravelling slopes and as a transition between other techniques and steep gradient natural riverbanks within restricted spatial areas. It will also be discussed how this approach can preserve existing mature trees on riverbanks while providing toe protection and habitat.

Lessons learned from monitoring various sites and recommendations for future applications will be presented.

TALK

Impact of natural disturbances and silvicultural activities on the protective function of forests, a case study in the Central Alps

LMW Rossi, A Cislaghi, S Oggioni, M Cavalleri, M Calvetti, G Vacchiano
Università degli studi di Milano, Department of Agricultural and Environmental Science

In Italy, 86% of forests play a crucial role in soil protection and water cycle regulation, yet climate change threatens their stability. Rising temperatures and increasingly frequent and intense extreme events, such as the 2018 Vaia windstorm and subsequent bark beetle outbreak, can reduce the provision of key ecosystem services by the damaged forests, especially the protective function against natural hazards. In this context, the assessment of the ecosystem services after natural and/or human disturbances is a key step for evaluating the forest resilience, monitoring the recovery of ecosystem service and implementing restorative silvicultural strategies.
This study was conducted on the mountain areas surrounding the municipality of Valdisotto (Valtellina, Lombardy, Northern Italy). In the study area, 142 hectares were affected by Vaia storm in 2018, later expanding to 186 hectares due to smaller scale wind damage in 2021 and a bark beetle (*Ips typographus*) outbreak exacerbated by summer drought in 2022-2023. Initial restorative actions such as salvage logging and tree planting were carried out in the damaged areas, with the intended aim to speed up forest regrowth and recovery of its environmental services. However, assessing the effectiveness of ongoing and planned restoration activities is crucial to devise effective actions and avoid unintended or counterproductive consequences. Our study aims to: (i) estimate the effect of natural disturbances and salvage logging on the decline of forest protective function against rockfalls and climate mitigation potential, and (ii) predict the pathway of forest recovery under different restoration scenarios (e.g., reforestation vs natural regeneration).

We measured forest composition and structure along gradients of disturbance severity (windthrow + bark beetle) and post disturbance management type (salvage logging vs. non-intervention). Data on tree species, size, and density were used to assess the provision of ecosystem services by the post-disturbance forest, i.e., protection against rockfalls using the simulator Rockyfor3D (Dorren, 2015), and carbon stocks using allometric equations. Moreover, we simulated forest composition, structure, and growth in the next 30 years using process based forest dynamics models 3PG and FORMIND under three scenarios: natural regeneration, active reforestation, and climate-smart forestry, and used simulated output to assess future protection against rockfall using Rockyfor3D .

Results show that tree species diversity declines immediately after a disturbance, but disturbance type and time since damage significantly influence species composition, with older bark beetle outbreaks after windthrow maintaining a higher species diversity compared to more recent disturbances or salvage logged areas. Canopy loss severely compromised rockfall protection, with the Rockfall Protection Index (RPI) dropping from pre-disturbance levels of 25–50% to 0–25% of falling rocks intercepted by the forest. Salvage logging and bark beetle exacerbated rockfall hazard. Among simulated forest management alternatives, selective thinning improved carbon sequestration by up to 20%, while tree planting and climate-smart forestry were most effective for restoring protection services by 2054.

This study underscores how climate-driven disturbances threaten mountain forests and their ecosystem services. It also identifies key management strategies—such as selective thinning, climate-smart forestry, and avoiding salvage logging—that can mitigate disturbance impacts and accelerate the recovery of key environmental services.

Dorren, L.: Rockyfor3D (v5.2) revealed – Transparent description of the complete 3D rockfall model, ecorisQ paper, Geneva, 32, www.ecorisq.org (last accessed: 2022), 2015.

TALK

Inventory of mass removal processes for the state of Veracruz
Yordan Emanuel Ruiz Meneses

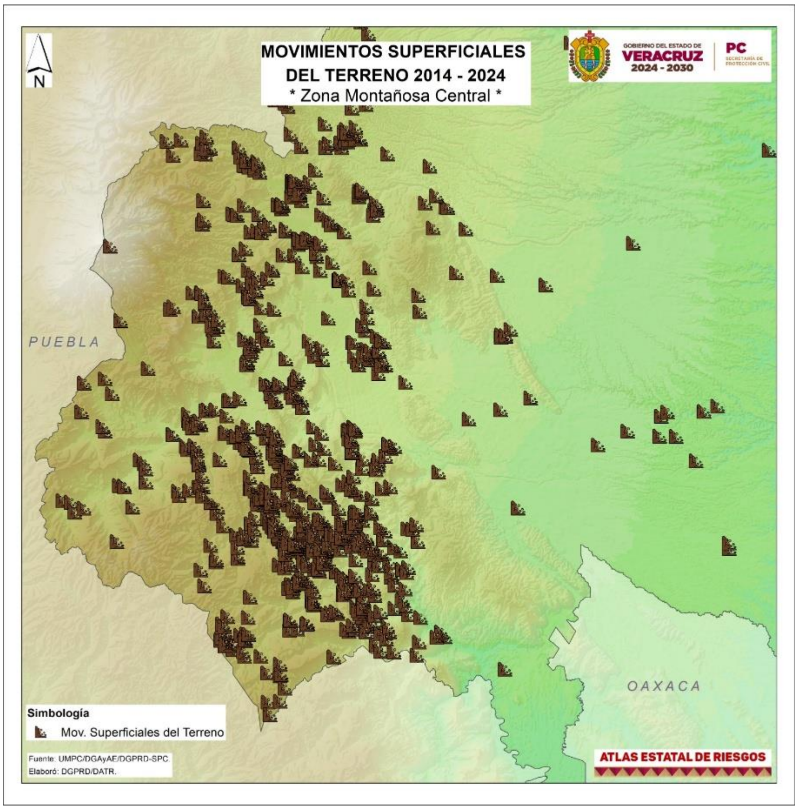
Secretaría de Protección Civil del Estado de Veracruz, Av. Lázaro Cárdenas 1104-B, Col. Revolucion, 91100 Xalapa-Enríquez, Ver.

Historical memory is a critical component of integrated disaster risk management and disaster risk reduction activities, as it improves our understanding of the frequency, scale and location of the impacts of various hazards.

In light of this, the Civil Protection Secretariat is developing the Inventory of Events in the State of Veracruz. This inventory includes data on socio-organisational phenomena, such as vehicle accidents and roadblocks. The latter encompasses a wide array of phenomena, including, but not limited to, forest and pasture fires, as well as the most recurrent in the state : geological and hydrometeorological phenomena. This inventory has four objectives : first, to provide input for regional risk analysis; second, to create a historical database of events; third, to deduce indicators of the social construction of risk; and fourth, to update susceptibility or peril layers for various phenomena.

The presentation will address the process of creating an inventory of geological phenomena, with a particular focus on mass removal processes. The challenges encountered during the course of the project will be addressed. The emphasis of the study will be placed on data capture, georeferencing, standardisation and, finally, the generation of a layer of information available for consultation on the Atlas de Riesgos del Estado de Veracruz (AREV) web platform.

The compilation of this inventory was initiated in 2021. However, the database under scrutiny identifies mass removal events that have occurred since 2014 and is subject to annual updates. The primary focus of these efforts is twofold: firstly, to update the inventory to create a more advanced version of a layer of susceptibility to mass removal events, and secondly, to produce information layers that break down other phenomena classified as non-geological phenomena, such as deaths due to immersion, vehicle accidents, and spills or releases of hazardous substances.



KEYNOTE SPEECH

Soil and Water Bioengineering, a Nature-based Discipline - Some European examples

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The European Environment Agency has recognized that only 15% of European habitats are in good condition, meaning that 85% of our life support systems are in poor or very poor condition, and degradation continues. The European Union, aware of the degree of degradation of our ecosystems, has set a strategy aimed at reversing biodiversity loss trends and accelerating the transition to a green economy and the efficient use of resources by 2050, so that biodiversity and ecosystem services can be protected, valued, and appropriately restored. -As part of this strategy was the adoption in 2024 of the Nature Restoration Law (NRL) whose ambitious targets – restoring at least 20% of land and marine areas by 2030 and almost all degraded ecosystems by 2050 – are binding for all EU countries.

This NRL here is a need to establish a National Restoration Plan, to be prepared by each country by mid-2026. This plan must be based on a clear diagnosis, on common and contrasting data and indicators, which will allow an action plan to be established with indications of good practices to follow to achieve the restoration goals set.

In this sense, Soil and Water Bioengineering (SWB), as Nature-Based Solutions (NBS), have proven to be an effective tool for restoration and for climate change mitigation and adaptation, and is therefore a very useful discipline to achieve the objectives of the Regulation

According to EFIB, Soil and Water Bioengineering is a discipline that combines engineering with biology, using native plants and plant communities as construction materials for soil erosion control in degraded environments. The term "engineering" refers to the use of technical and scientific data for construction, stabilization, and erosion control purposes, and "bio" because these functions are related to living organisms, mainly native plants, with biotechnical properties, and to restore ecosystems and increase biodiversity. In this approach, the potential of native plant communities is a key factor in achieving the overall objectives of planned interventions. SWB work designs involve both the integration of intrinsic adaptive information processes and legitimate design

Soil and water bioengineering provide sustainable solutions to mitigate and adapt to climate change, and effective restoration approaches suitable for degraded situations. The practice of SWB is in line with the principles of NBS, "inspired and supported by nature" that provide sustainable, cost-effective, versatile, and flexible alternatives for different objectives: technical, environmental, landscape Integration, and socioeconomics. As well as Soil and Water Bioengineering do

Accompanying this presentation with a selection of examples, works, publications and projects of EFIB members.


P.Sangalli Baztar River (Spain)

Bioingeniería del Paisaje : Una disciplina basada en la Naturaleza . Ejemplos europeos
P. Sangalli

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La Agencia Europea de Medio Ambiente ha reconocido que solo el 15 % de los hábitats europeos se encuentran en buen estado, lo que significa que el 85 % de nuestros sistemas de soporte vital están en mal o muy mal estado, y la degradación continúa. La Unión Europea, consciente del grado de degradación de nuestros ecosistemas, ha establecido una estrategia destinada a invertir las tendencias de pérdida de biodiversidad y acelerar la transición hacia una economía verde y el uso eficiente de los recursos para 2050, de modo que la biodiversidad y los servicios ecosistémicos puedan protegerse, valorarse y restaurarse adecuadamente. -Como parte de esta estrategia, en 2024 se adoptó el Reglamento de Restauración de la Naturaleza (NRL), cuyos ambiciosos objetivos —restaurar al menos el 20 % de las zonas terrestres y marinas para 2030 y casi todos los ecosistemas degradados para 2050— son vinculantes para todos los países de la UE.

Esta NRL establece la necesidad de elaborar un Plan Nacional de Restauración, que cada país deberá preparar para mediados de 2026. Este plan debe basarse en un diagnóstico claro, en datos e indicadores comunes y contrastados, que permitan establecer un plan de acción con indicaciones de buenas prácticas a seguir para alcanzar los objetivos de restauración fijados. En este sentido, la bioingeniería del Paisaje (SWB), como solución basada en la naturaleza (NBS), ha demostrado ser una herramienta eficaz para la restauración y la mitigación y adaptación al cambio climático, por lo que es una disciplina muy útil para alcanzar los objetivos del Reglamento.

Según la EFIB, la Bioingeniería del Paisaje es una disciplina que combina la ingeniería con la biología, utilizando plantas autóctonas y comunidades vegetales como materiales de construcción para el control de la erosión del suelo en entornos degradados. El término «ingeniería» se refiere al uso de datos técnicos y científicos con fines de construcción, estabilización y control de la erosión, y «bio» porque estas funciones están relacionadas con organismos vivos, principalmente plantas autóctonas, con propiedades biotécnicas, y con la restauración de ecosistemas y el aumento de la biodiversidad. En este enfoque, el potencial de las comunidades vegetales autóctonas es un factor clave para alcanzar los objetivos generales de las intervenciones previstas. Los diseños de los trabajos de SWB implican tanto la integración de procesos de información adaptativa intrínseca como un diseño legítimo

La Bioingeniería del Paisaje proporciona soluciones sostenibles para mitigar y adaptarse al cambio climático, así como enfoques de restauración eficaces adecuados para situaciones degradadas. La práctica de la SWB está en consonancia con los principios de las NBS, «inspiradas y respaldadas por la naturaleza», que ofrecen alternativas sostenibles, rentables, versátiles y flexibles para diferentes objetivos: técnicos, medioambientales, de integración paisajística y socioeconómicos. Al igual que la bioingeniería del suelo y el agua,

Acompañamos esta presentación con una selección de ejemplos, trabajos, publicaciones y proyectos de los miembros de la EFIB.


P. Sangalli Río Baztar (Spain)

TALK

Temporal Dynamics of Root Reinforcement in Bioengineering Measures: A Case Study of Grey Alder and Norway Spruce Succession

M. Schwarz, K. von Wattenwyl, H.M. Ngo, P. Aebischer

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The quantification of the spatio-temporal dynamics of root reinforcement and temporal technical measures, such as wood-cribwalls, is crucial for assessing the time-dependent effectiveness of bio- and ecoengineering measures. While quantitative analyses in the literature are limited to specific vegetation stages, this study presents a comprehensive approach to effectiveness analysis using a case study in the Canton of Fribourg, Switzerland. The former pastureland "Upper Eltschingera" has evolved over 17 years through natural and artificial regeneration into a young forest of grey alder (*Alnus incana*) and Norway spruce (*Picea abies*), serving as protective forest for an alpine hut. The study analysed the successive replacement of the pioneer species grey alder by spruce. To model the temporal dynamics of root reinforcement, root tensile strength was investigated through field pull-out tests, and root reinforcement were calculated based on root distribution using the Root bundle model (RBMw). Allometric relationships enabled spatial and temporal representation of root reinforcement at the stand level. Using root reinforcement data and other fundamental inputs, the slope stability model SlideforNET calculated the probability of shallow landslides, allowing assessment of the need for temporary technical measures.The modeling revealed that the pioneer phase of grey alder can significantly contribute to preventing shallow landslides, particularly between 10 to 40 years after establishment. Interestingly, the dynamics of grey alder showed little difference between planted and naturally regenerated trees. The study conceptually demonstrated an integrated approach for time-related effectiveness analysis of bioengineering measures. This research provides valuable insights into the long-term efficacy of bioengineering techniques in slope stabilization, emphasizing the importance of considering species succession and temporal root reinforcement dynamics in nature-based solutions.

Keywords: *Alnus incana*, *Picea abies*, Root reinforcement, Ecological Engineering, Protection Forest, Forest management, NbS, Time dependency, Shallow landslides.

KEYNOTE SPEECH

Mass movements on volcanic slopes in Mexico

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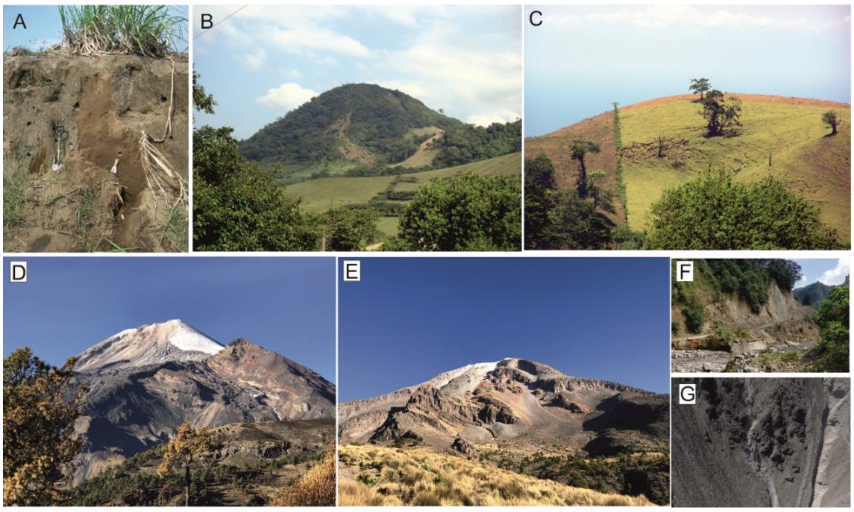
Mountainous regions in Mexico are highly prone to mass movements, particularly during the seasonal heavy rainfall and following major earthquakes. Since the Tertiary period, active volcanism—caused by the subduction of the Cocos and Rivera oceanic plates—has given rise to the Trans-Mexican Volcanic Belt (TMVB), which extends from west to east and partially overlaps with several other Mexican mountain ranges. The TMVB comprises thousands of volcanic structures, including a smaller number of long-lived polygenetic volcanoes and extensive volcanic fields containing hundreds of smaller, short-lived monogenetic volcanoes.

Elevations within the TMVB range from just a few meters above sea level near the coasts to over 5,000 meters above sea level, resulting in diverse climatic and vegetation zones both along the belt and compared to the surrounding lowlands. At the highest volcanic peaks, such as Pico de Orizaba and Popocatépetl, past glaciations have shaped the edifice, and the recent retreat of glaciers has exposed unstable, weathered material. These high-altitude areas are furthermore characterized by conditions with intense physical weathering and wind erosion. Rock falls dominate on these steep upper slopes, while debris flows (lahars) are the primary mass movement hazard on the middle and lower flanks.

The volcanic edifices of many active or dormant volcanoes of the TMVB also experience hydrothermal activity, which further contributes to slope instability. In contrast, the deposits associated to volcanic edifices located in tropical climate zones tend to weather rapidly and become covered by dense vegetation. Here, for example in the Tuxtlas volcanic field to the S of the TMVB, mass movements are dominated by various types of flows and soil creep, especially in areas where deforestation has occurred.



A-lahar deposit in the Los Tuxtlas volcanic field (LTVF); B-mud-flow (scoria cone flank, LTVF); C-creep on a flank of an eroded and deforested scoria cone (LTVF); D and E – N and S-flank of Pico de Orizaba (PO)volcano respectively; F-old bridge destroyed by a recent lahar event at PO volcano; G-drone image of high-elevation (above 4500 m asl) flow channels at the N-flank of PO volcano

TALK

Defining Resilient Nature-based Solutions for riverbanks stabilization using species distribution models with 2050 climate projections

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Riparian ecosystems form the transition between aquatic and terrestrial ecosystems. With their position and their multiple ecological functions, they play a crucial role in protecting and regulating rivers, serving as biodiversity hotspots and providing multiple ecosystem services[1]. However, the construction of various infrastructures to support human development has disrupted these areas, often exacerbating erosion and degradation of these ecosystems, reducing their adaptive capacity to climate change. Furthermore, efforts to protect human infrastructure usually rely on artificial bank protection using traditional civil engineering techniques. While these solutions stabilize the riverbanks, they can compromise ecological functions and disrupt biodiversity dynamics.

In this context, the use of Nature-based Solutions (NbS) offers a sustainable alternative for restoring and protecting these ecosystems while addressing societal challenges such as climate change mitigation and adaptation, environmental degradation and biodiversity loss, disaster risk reductions, economic and social development, water security, and human health[2]. Among NbS, soil and water bioengineering use living vegetation as the stabilization material, providing engineering benefits while promoting the natural conditions that can support the maintenance of biodiversity and associated ecological functions[3].

Despite its potential to stabilize riverbanks while protecting ecological functions and ecosystem services, its adoption remains limited due to uncertainties about long-term evolution and challenges in demonstrating their resilience to climate change. Addressing these limitations is essential to understand the effectiveness of soil and water bioengineering, ultimately promoting the integration of these solutions as a key tool for adapting riverbanks to the challenges of climate change.

This research aims to assess the resilience of soil and water bioengineering techniques for riverbank protection in France. Using species distribution models[4,5], the study analyzes the vulnerability of natural and implemented vegetation structures under different climate scenarios. By applying 2050 climate projections (SSP2-4.5 and SSP5-8.5), it evaluates potential risks for vegetation survival and consequently to the stability of these structures. This methodology aims to provide useful insights for designers and decision-makers, helping them build structures better adapted to climate change.

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TALK

Centrifuge modelling of vegetated slopes under rainfall: incorporating tree weight and canopy interception

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Vegetated slopes exhibit enhanced stability compared to bare slopes due to the mechanical and hydrological effects of vegetation. Tree roots reinforce the soil through mechanical reinforcement and water uptake, while the canopy intercepts rainfall, reducing surface runoff and erosion. While centrifuge modelling has been used to investigate the behaviour of vegetated slopes under various conditions, the combined effects of root reinforcement, canopy weight, and rainfall interception have not been fully explored. Existing centrifuge models often simplify or neglect the contribution of tree weight and canopy, limiting the accuracy and realism of the simulations. This research aims to address this gap by developing a novel centrifuge modelling technique that incorporates the effects of tree weight and canopy interception on slope stability under rainfall. For that, a series of centrifuge tests are conducted on 45-degree slopes made of pure sand. Three test conditions are investigated: (1) bare slope; (2) rooted slope, where 3D models of a tree root system is used to create the root replicas via 3D printing, ensuring accurate representation of root architecture and mechanical properties; and (3) vegetated slope, where the root models mentioned in (2) are combined with 3D printed plate structures designed to mimic the weight and leaf area index of a real tree canopy. For all test conditions, slope failure will be induced by triggering multiple rainfall events coupled with rising water table. The centrifuge tests are expected to provide detailed data on the soil deformation and pore water pressure evolution within the slope under different test conditions. Also, observed failure mechanisms are expected to vary between the three test conditions, reflecting the different stabilizing mechanisms provided by roots and canopy. The novel centrifuge modelling technique developed in this study will provide a valuable tool for investigating the effectiveness of different vegetation types in stabilizing slopes under various rainfall conditions. The findings of this study will facilitate soil-root interaction model validation and have implications for designing and implementing effective bioengineering solutions for slope stabilization and erosion control.

Keywords: centrifuge modelling, vegetated slopes, rainfall-induced landslides, canopy interception

KEYNOTE SPEECH

Make soil while the sun shines - how plants influence soil cohesion

A. Stokes
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This talk will explore how photosynthesis in plant leaves has a direct effect on soil cohesion through the action of root growth and microbial activity. As plant roots grow through soil, carbon is exuded through pores and used as a substrate for microbial communities. This carbon then passes through a chain of microorganisms where it can be excreted as extracellular polymeric substances (EPS) that increase cohesion and can be captured onto the finer silt and clay particles in soil. How and if artificial EPS can be used to improve cohesion will be examined, along with the influence on soil mechanical properties. Finally, suggestions are made for the most useful plant species for fixing soil on slopes, depending on their microbial associations.

TALK

Slope stabilisation by bio-technical `net´

M. Šubic

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For permanent slope stabilisation, the plant (biological stabilisation) and structure (technical stabilisation) have to be used in an integrated fashion. Stability is provided by slide pressure dispersion through the plant-structure net. The `net effect´ is maximized where slopes are convex in shape. `Net effect´ is illustrated on applied Biotechnical methods.

When vegetation is growing on unstable sloping areas, it forms a natural root protection net. Unstable areas can transfer slide pressure along the net and thereby receive support. Stability is therefore provided by slide pressure dispersion. Additionally, roots can also improve the shear strength of the soil by a factor of from three to five times. Slope stabilisation by natural tensile root netting is maximized where slopes are naturally convex shaped. Excess rain water can run off vertically and energy is able to be absorbed by the forest floor, usually without damage being caused. Man made drainage takes the excess water away in horizontal channels. Over a period of time, the horizontal drainage structure can itself become a destabilizing factor because it interrupts the root net continuity and the benefits of a proper convex contour are also lost.

To establish forest vegetation on steep slopes, we have to achieve initial stability of the slopes, reduce kinetic energy of water run off and provide good growing conditions. This will be achieved largely by technical means at first. Once the technical support is given, vegetation can be planted on the slopes. A technical solution enhances the stabilisation effect through the creation of high tension between the soil covering the net and the static or moving soil under the net. This netting strategy, when applied together with convex shaping (Fig 3) of the slope and the weight based stabilisation of the material on the net, will create additional tension between the soil and the covering wire, as a natural forest does. As indicated in the drawing below, a curved surface redirects lateral pressure into the soil below.

Potential localised sliding will produce pressure, which netting on the convex shaped slope will then disperse laterally on the slope. On a convex slope, lateral pressure is turned into pressure into the slope itself, bringing more compression and enhancing slope stability.
Experience shows that shallow landslides are not common in the forest. Nature produces living mechanisms to protect against slippage. In the forest, 70% of sliding soil pressure is dispersed by the `net effect´ created by the lateral roots of plants (also the purpose of our man-made net) and 30% by the anchoring tap sinker roots (our soilnails). This means that most of the stabilisation effect is facilitated by the net's dispersion effect. This conclusion is in accordance with Nillaweera 1996 field evidence, Yoshinori Tsukamoto/Osamu Kusakabe 1984 and Riestenberg 1994.

The Bio-Technical approach seeks to achieve the optimum effect by utilizing the benefits of both the technical and biological methods. In my opinion this offers the most effective and permanent slope stabilisation solution.

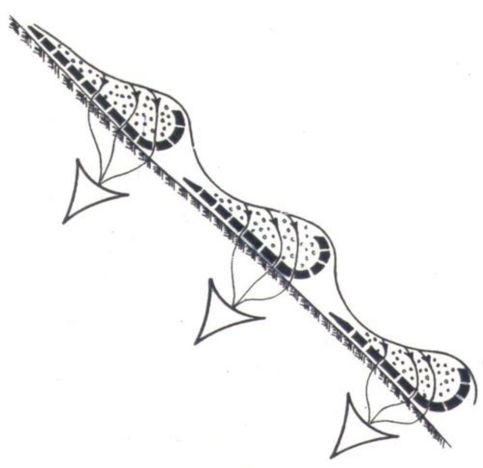

Fig. 1 Shows how good growing conditions can be provided by ensuring adequats soil moisture. On a steep, bare slope, where water flows away fast, the conditions are unfavorable to the development of covering vegetation. Terraces will retain the water and conduct it into the soil (F. Subic 1991 in M. Subic 1996)

TALK

How do root mechanical traits at the yield point vary and why is it useful to estimate them?

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Root mechanical traits are of crucial importance in plant physiology and ecology. These traits serve as fundamental indicators of root growth capacity and functional performance, and are also key parameters for assessing a plant's ability to mitigate geohazards. While most of the existing studies predominantly focus on the tensile strength and strain of roots at the breaking point, few of them have paid attention to those at the yield point. At the yield point, the tensile behavior of a root undergoes a significant change from the elastic phase to the plastic phase. A more sophisticated characterization of such transition in root mechanical behavior is vital for a better understanding of plant performance in ecosystems. How do root mechanical traits at the yield point vary? To what extent do these traits at the yield point covary with those at the breaking point? Here, we used published datasets to investigate root tensile strength and strain at the yield point and those at the breaking point, respectively. By analyzing these traits at both intra- and interspecific levels, we aims to elucidate the complexity in the biomechanical design of root tissues, as well as its potential ecological implications.

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TALK

Internal erosion resistance by plant roots and subsequent shearing

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Internal erosion refers to the seepage-induced movement of fine particles within a soil matrix and is a common failure mechanism in earthen hydraulic structures. The behaviours of soil subjected to internal erosion have been widely investigated, yet the root reinforcement effects in internal erosion resistance under different stress paths have never been explored. Moreover, there is a lack of knowledge on how plant roots provide resistance to internal erosion due to the anisotropy in the soil structure and root system. This study aims to investigate the hydromechanical behaviour of soil reinforced by vetiver grass (*Chrysopogon zizanioides L*) under different stress paths during erosion and post-erosion shearing and volumetric behaviour. A new apparatus, back-pressure-controlled triaxial permeameter (Fig. 1) that is equipped with Hall-effect transducers and bender elements was developed for testing. Changes in fabric anisotropy during erosion under both isotropic and extension path (i.e. 50 kPa) were measured by sending waves in the vertical direction polarising in horizontal direction and horizontal direction but polarising in both vertical and horizontal directions. Subsequently, undrained triaxial extension was applied at each confinement to determine any changes in the stress-strain behaviour. Any erosion-induced evolutions in shear modulus and its anisotropy under both stress paths will be presented and discussed. Effects of stress path on the post-erosion shearing and volumetric behaviour including dilatancy also will be investigated. Based on the interpretation of the new test data (Fig. 2) and existing state-of-the-art understanding of internal erosion, the mechanisms of fine particle transport with root reinforcement and soil microstructure changes under both isotropic and extension path during erosion and how interaction of roots with fine migration affects the anisotropic post-eroded shearing and volumetric behaviour will be discussed.

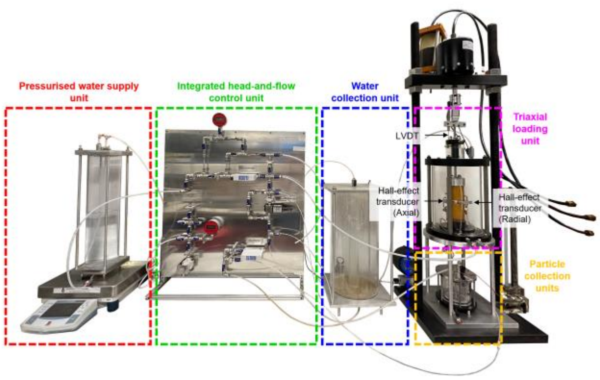

Figure 1: The newly developed back-pressure-controlled triaxial permeameter for internal erosion tests.

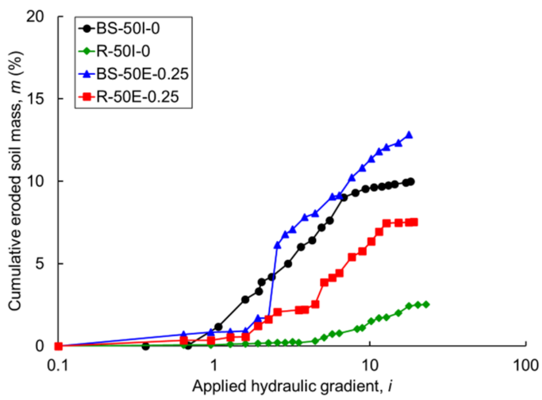

Figure 2: Variation in cumulative eroded soil mass (normalised by the total weight of the fine-grained soil) with the applied hydraulic gradients.

TALK

Soil Microbial Diversity and Erosion Control: Insights from Alpine Forests Under Disturbance

H. Terol, E. Gadrat, A. Shihan, L. Selli, Mao Zhun, A. Stokes

INRAE, AMAP, University of Montpellier, CIRAD, CNRS, IRD, Montpellier, France

Soil stability and resistance to erosion are critical to sustaining terrestrial ecosystems and preventing land degradation. Soil, as a biodiversity reservoir, hosts microorganisms (bacteria, fungi, protists, viruses, etc.) that play essential roles in maintaining soil structure, nutrient cycling, and ecosystem functioning. These microorganisms, acting as ecosystem engineers, contribute to soil aggregate formation and stability, mitigating erosion risks. In forest ecosystems, microbial communities interact with root systems and soil particles, enhancing carbon (C) storage and resilience against physical disturbances. However, the impact of forest management practices on soil stability through their effects on microbial diversity and function remains poorly understood. Disturbances such as tree species shifts, thinning, soil amendments, and anthropogenic activities (e.g., ski slope construction) may significantly influence soil microbial diversity and, consequently, soil erosion processes.

We hypothesize that: (i) disturbances induced by forest management disrupt soil microbial communities, weakening their role in soil stabilization; (ii) rhizospheric interactions between microorganisms and root traits protect soil from erosion and enhance soil structure, particularly in minimally disturbed forests; and (iii) soil properties shaped by management interventions determine microbial contributions to aggregate stability and erosion control.

To address these hypotheses, we analyzed microbial diversity and soil physical properties across a disturbance gradient in the French Alps, focusing on areas within the Chamrousse ski resort. Soil samples were collected from 11 plots under *Pinus uncinata* trees, representing pristine forests, degraded zones near ski slopes, and ski slopes themselves. Three additional control plots were sampled outside the skiing area. Samples included vegetation cover, litter, bulk soil (A, B, and C horizons), rhizospheric soil, and fine roots. Tree traits, vegetation species, and biomass measurements were recorded alongside soil stability indicators.

Microbial diversity was assessed using metabarcoding of bacterial (16S rDNA) and fungal (ITS) markers, while functional diversity was evaluated through Community-Level Physiological Profiling (CLPP) and soil respiration assays. Soil physical and chemical analyses included texture, bulk density, organic matter fractions, nutrient content, and aggregate stability. A custom wet sieving method was employed to determine soil aggregate size distribution and stability, with plans to correlate microbial composition within aggregates using metabarcoding.

Multivariate analyses are being conducted to explore how forest management practices influence microbial diversity, soil properties, and their interrelationships with soil stability and erosion resistance. The findings will provide insights into sustainable management strategies to preserve soil integrity in forested landscapes.

TALK

Characterization of Mechanical Properties of Plant Roots Based on Paricle Image Velocimetry

Yuling Xiao [1,2], Jinnan Ji [1,2], Sicen Li [1,2], Yuzhe Yang [1,2]
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The tensile strength, elastic modulus, strain, and other mechanical parameters of plant root systems serve as crucial indicators for evaluating their soil reinforcement capabilities. Traditional tensile tests estimate engineering strain by measuring overall displacement. However, plant roots, being biological materials, inevitably exhibit grip slippage between the jaws of the universal testing machine and the root samples during testing, leading to inaccuracies in the mechanical parameters and subsequently influencing the assessment of the soil reinforcement capabilities of the root system. This study proposes a novel method that integrates Particle Image Velocimetry (PIV) with tensile testing: tracer spots are prepared on the root surface, and PIV is utilized to dynamically track the displacement field of two marked points during the tensile process to calculate local true strain and inversely derive mechanical parameters such as the elastic modulus. A comparison with the engineering strain results from traditional tensile tests reveals the following: (1) The true strain values are lower than the engineering strain obtained by traditional methods, and the strain error at the yield point is smaller than that at the maximum tensile force point; (2) There is a positive correlation between root diameter and strain error, attributed to the amplified effect of non-uniform deformation caused by the heterogeneous structure of coarse roots; (3) The elastic modulus corrected based on PIV is larger than the traditional value, confirming that traditional methods underestimate material stiffness due to neglecting geometric nonlinearity. This study validates the precision advantages of PIV technology in the mechanical characterization of roots and provides high-resolution strain data support for quantitative analysis of the plant root-soil interaction mechanism.

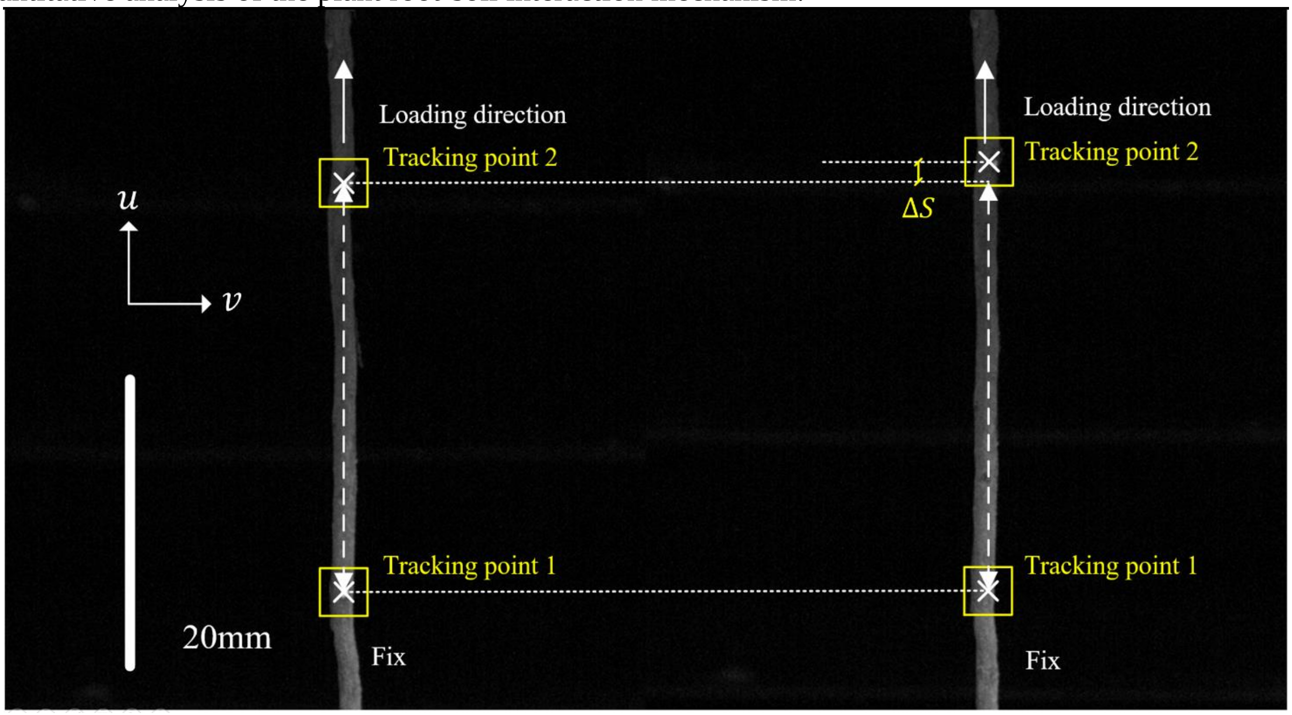

Figure Schematic diagram of PIV measurement for root tensile testing

TALK

Considering the asymmetrical configuration of a landslide greatly shifts slope stability assessment

Yuzhe Yang [1,2], Jinnan Ji [1,2], Zhun Mao [3]

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Slope stability assessment is a key step in landslide mitigation practices. Most current slope stability models rely on infinite or symmetrical finite slope configurations with equal flank scarp angles. However, real landslides often involve asymmetrical finite slopes, and the impact of incorporating such configurations into models remains uncertain. Here, we aim to propose a new slope stability model that allows to consider the asymmetry of a finite slope with unnecessarily equal flank scarps. With that, how the variation of unequal flank scarp angles impacts the assessment of slope stability was evaluated. To compare the three configurations (i.e., infinite, symmetrical finite and asymmetrical finite slope), we first calculated the factor of safety (FoS) using measured size and flank angles of 10 shallow landslides in the Loess Plateau. Then, sensitivity analyses were performed using randomized flank angles to explore the differences that the three configurations could theoretically achieve. We observed a significant difference in FoS estimates between infinite and finite slope configurations. Utilizing data from actual landslides, the finite slope configurations tended to provide more conservative FoS estimates compared to the infinite slope configuration. Additionally, for the same slope angle, the asymmetric slope configuration with unequal flank angles resulted in notably lower FoS estimates than the symmetric configuration with equal flank angles. Our results highlight the importance of considering unequal flank angles in slope stability assessments, yielding conservative FoS values compared to traditional models. This finding provides useful guidelines for improving slope stability modeling and landslide mitigation practices.

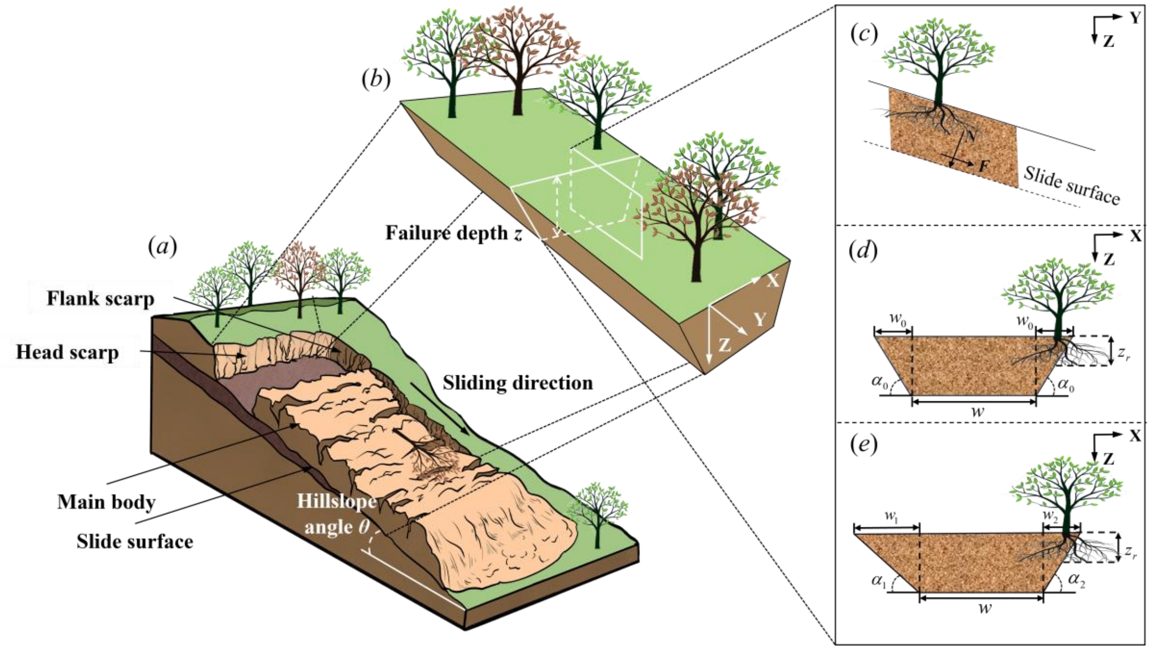

Figure. 2 Illustration of a translational shallow landslide (*a* and *b*) and three ways of slope configuration in slope stability modelling, including infinite slope (*c*), symmetrical finite slope (*d*), and asymmetrical finite slope (*e*). In (*c*), *N* and *F* represent normal load and load parallel to the slope, respectively; in (*d*), w_0 is the horizontal projection length of equivalent midst flank scarp; in (*e*), w_1 and w_2 represent horizontal projection lengths of the left and right flank scarp, respectively.

KEYNOTE SPEECH

Improving Forest Hydrological Services Under a Changing Environment: Practices in China

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Widespread deforestation has greatly degraded water-related ecosystem services provided by forests in China in the last century. The nation-wide catastrophic floods in China in 1998 is a good example of severe ecological consequence of forest loss. Since then, China has launched a series of forest restoration projects including Natural Forest Protection Program (NFPP) and Sloping Land Conversion Program (SLCP) to combat deforestation. The massive forestation makes China the country with the largest contribution to land greening on Earth in the past two decades. Water-related ecosystem services such as flood control, water supply, soil erosion control, flow regulation, and climate regulation provided by forests have been enhanced accordingly due to national-wide efforts in forest restoration in China. Here we will use the studies in the Upper Yangtze River basin and the Loess Plateau as examples to demonstrate how we restore water-related ecosystem services of subalpine and temperate forests by regional-specific forest management practices in China. These findings can provide important scientific supports for restoring water-related ecosystem services of forests by adaptive forest management under a changing environment in China and other countries.

TALK

Simple-shear and direct-shear behaviours of rooted soils

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The direct shear test (DST) and simple shear test (SST) are commonly used to evaluate the shear strength of soil. DST, favored for its simplicity, is widely applied to rooted soils but imposes a predefined shear plane, failing to replicate stress path of soil element before slope failure. In contrast, SST better simulates shear behavior but is underutilized in assessing root effects on soil shear strength and dilatancy. This study performed DSTs and SSTs on soil reinforced with vetiver grass roots (*Chrysopogon zizanioides L.*) to measure strength and dilatancy (Fig. 1 (b, c)). Results revealed that DST consistently overestimated shear strength and dilatancy (Fig. 1 (a)), with effective cohesion of rooted soil often exceeding 100%. Rooted soils exhibited maximum dilatancy at lower shear strain levels than their peak shear strength, contrasting with bare soil behavior. A new stress-dilatancy model was developed to quantify the effects of root-induced dilatancy on peak friction angle under plane-strain conditions. Sensitivity analyses demonstrated that shallow-rooted soils exhibited more pronounced dilatancy effects due to increased root biomass and enhanced effective cohesion. Whereas Stability analyses of vegetated slopes showed that DST-derived strength parameters significantly overestimated the factor of safety (FOS), highlighting potential risks in engineering design. Including root-induced dilatancy increased the FOS but to a lesser extent than the impact of root cohesion. These findings emphasize the need for caution when using DST for rooted soils and highlight the importance of considering both root cohesion and dilatancy effects in stability assessments and engineering applications.

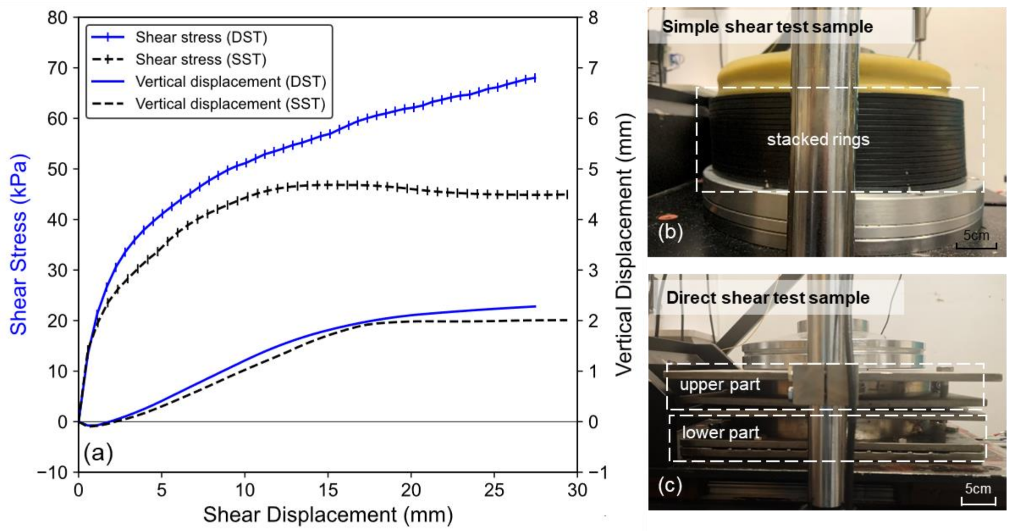

Figure 3 (a) Shear stress - shear displacement and vertical displacement - shear displacement curves of the rooted specimens at normal stress of 50 kPa; (b) sample container for simple shear test; (c) sample container for direct shear test.

TALK

The Strange Case of the Lower Murray Riverbank Failures at Long Island Marina: an example where riparian trees probably promoted rather than prevented bank failure

Jiale Zhu and Thomas Hubble
The University of Sydney, NSW, Australia

Several highly unusual riverbank failures occurred on the lowermost reaches of Australia's Murray River between 2008 and 2010 during the period of peak aridity extant towards the end of the 'Millennium' drought. This drought was a long-lived event that effected the entire Murray-Darling catchment and much of southern Australia between 1996 to 2010 – it was broken by two years of pronounced La Nina conditions and a return to average flow conditions with small to moderate floods. Between 2008 and 2010 the water surface of the Murray River's lowermost reaches gradually fell to levels almost two metres below normal pool level (and 1.5 metres below sealevel) over a period of 12 months. This was enabled by the isolation of the lower river channel from the sea by a system of barrages located at the river mouth. Most of the failures occurred without warning and one event, at Long Island Marina in February 2009, very nearly caused a fatality and resulted in the 'deposition' of three cars within the adjacent Murray River Channel.

These drought-associated bank failures are particularly unusual, as most large-scale riverbank failures occur due to toe-scour or post-flood draw-down effects associated with flood recession. Previous work has identified that several factors contributed to these unusual instances of riverbank failure. They include: 1) over-steepened banks associated with deep scour holes eroded into the channel floor; 2) the ubiquitous presence of relatively impermeable soft clays that form the banks; and 3) the unusual lowering of the river's water surface which generated a rapid-drawdown like effect, but in slow motion.

This work will investigate the role of the surcharge weight of shallow-rooted riparian trees in promoting failure and the possibility that wind throw or wind stress may have contributed to weakening of the bank soils or actually triggered failures.

POSTERS

POSTER

What Tree Species Are Suitable for Slope Stabilization? A Case Study in a Mid-Elevation Forest of Central Veracruz, Mexico

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Instituto de Ecología, A.C. Red de Ecología Funcional. Xalapa, Veracruz. C.P. 91073. Mexico.

The tropical montane cloud forests of central Veracruz, Mexico, are located on steep slopes that are increasingly vulnerable to geomorphological disturbances. Ongoing deforestation, combined with climate change and the intensification of dry spells, has contributed to soil degradation and the formation of gullies and shallow landslides. During intense rainfall events, water infiltration into the soil can trigger runoff and slope failures, particularly in areas where vegetation has been removed or degraded.

Conventional strategies to mitigate slope instability in the region often rely on the application of cement slabs to reinforce soil structure, prevent further erosion, and stabilize surface fissures. While effective, such engineering solutions are costly, environmentally intrusive, and do not contribute to long-term ecosystem restoration. As an alternative, the strategic use of vegetation—especially tree species with appropriate functional traits—offers a nature-based solution that can enhance slope stability while contributing to ecological recovery.

Although bamboo has been widely documented as effective for soil reinforcement due to its dense root systems, some tree species also possess structural, anatomical, and physiological traits conducive to slope stabilization. While the use of native species is generally preferred for ecological restoration, we argue that not all non-native species should be excluded *a priori*. The studied non-native tree may offer functional advantages under specific environmental conditions, especially where native species may be limited by ecological constraints such as water stress or slow growth.

In this study, we evaluated both native and non-native species for their potential contribution to slope stabilization. Among the native species, we considered small trees such as *Wigandia urens*. As a non-native candidate, we focused on *Eriobotrya japonica*, a small to medium-sized tree with notable high drought resistance, low relative growth rate in understories but fast growth in gaps, and an outstanding resprouting response. These traits suggest that *E. japonica* could contribute to both mechanical soil reinforcement and hydrological regulation on degraded slopes. Our case study emphasizes the functional characteristics that make *E. japonica* a potentially suitable species for slope stabilization in this mid-elevation tropical forest.

POSTER

Comparison of root cohesion models at a shallow landslide in the Oregon Coast Range, USA

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Plant roots are critical for slope reinforcement against shallow landsliding, yet accurate quantification of root reinforcement remains an ongoing challenge. Back-calculation of root cohesion at observed landslide sites is generally not possible due to lack of information about the distribution and properties of roots along the failure surface. However, a unique dataset collected immediately following the shallow landslide at CB1 in the Oregon Coast Range represents an opportunity to accurately compute root cohesion using detailed root data collected at the time and place of a known landslide (CB1). In this study, we use the field data from CB1 to estimate root cohesion using three different root breakage models developed over the last several decades: the Wu and Waldron Model (WWM), which assumes simultaneous failure of all roots; the Fiber-Bundle Model (FBM), a stress-controlled model in which load is progressively redistributed as roots fail; and the Root-Bundle Model-Weibull (RBMw), a strain-controlled model which accounts for both the effects of elastic deformation as well as the variability in strength among roots of the same diameter.

Results indicate that the root cohesion estimate depends significantly on which root breakage model is used for computation. Importantly, root cohesion values at the CB1 computed using the WWM were published in a previous study prior the development of newer models such as the FBM and RBMw. Estimates of scarp-averaged cohesion from the RBM and RBMw models are 1.2 kPa and 0.8 kPa, respectively, approximately 74-82% lower than the initial estimate of 4.6 kPa obtained using the WWM model. Although it is well-known that the assumptions of the WWM are unrealistic and likely lead to overestimation, these results indicate that the WWM-estimated values are overestimated by a factor of 4-5 at CB1, even greater than the factor of approximately three found in other studies. In addition, root cohesion values from the previous study at CB1 have been cited in other publications, and these values should be used with great discretion as they are likely overestimated.

All three models indicate that root cohesion has substantial spatial heterogeneity, with most parts of the landslide scarp having little to no root cohesion and areas of high root cohesion concentrated near plant roots. Additionally, the contribution of root cohesion by plant species differs substantially among the models. When compared to the FBM, the RBMw indicates a distribution of root cohesion contribution which is more consistent with field observations and reflects that the RBMw accounts for control of resisting forces over a broader range of displacements. Overall results indicate the importance of models with physically realistic assumptions which account for the mechanical processes governing root behavior, such as differential displacement and load redistribution.

POSTER

Augmenting the regeneration of vegetation in mountain chir pine forests through *low-cost in-situ* soil moisture conservation measures

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Chir pine (*Pinus roxburghii*) is one of five Pinus species in the Himalayan mountain ranges of India. It is important coniferous species in the Himalayan region, up to 2500m and is of great ecological, silvicultural and economic importance. But the regeneration of understorey vegetation was poor growth in this forest types because of forest fire, poor soil, thick layer of litters, steep slope terrain condition, small growth season periods, loss of fertile land. The present study was conducted in the *P. roxburghii* forest area at Mussoorie forest division, Uttarakhand. Eight treatments (T1-Shallow ditch-I, T2-Shallow ditch –II, T3-Shallow trench, T4-Earthen bund, T5-Pine needle bund, T6-Earthen bund + grasses, T7-Pine needle bund + grasses, and T8-Control) with varying depths and lengths were applied in the field to evaluate the effect of different soil moisture conservation (SMC) measures on regeneration of understorey vegetation. Among the SMC treatments, the maximum value of understorey plant density, frequency and abundance averaged over all seasons and aggregated for all plant types, was noted in the T2 treatment i.e. 22.1 individuals per m^2, 144.2 %,47.3 respectively compared to control treatment i.e.10.7 individuals per m^2, 60.7% and 33.1. During the study six different tree seedling were recorded i.e., *Pinus roxurghii, Lyonia ovalifolia, Quercus leucotrichophora, Myrica esculenta, Rhododendron arboretum, Prunus cerasoides.* Five types of shrub species (*Berberis aristata*, *Ageratina adenophorum*, *Flemingia strobilifera*, *Myrsine africana*, *Rubus ellipticus*) growth and 27 species of grasses were recorded on the site. Thus results indicated that the deployment of SMC treatment significantly augmenting the understorey vegetation growth on difficult and steep slope site. It is nature based and cost effective solution to enrich forest biodiversity and reduce soil losses from forest area. The results will help in effective management of pine forest, enhancing the ecosystems services, improving the productivity of forest and meeting the fodder requirement of local people for livestock's.

Key words: Diversity, Forest, Low-cost, Understorey vegetation

Soil and Water Bioengineering (SWBE): Slope Stability Evolution and Multi-Taxon Diversity Monitoring in a Restored Shallow Landslide in Tuscany

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Ecological restoration of degraded landscapes increasingly relies on Nature-Based Solutions (NBS) to enhance ecological processes, restore biodiversity, and fulfil technical-functional purposes. Soil and Water Bioengineering (SWBE) interventions combine engineering functionality with environmental restoration, taking advantage of plants to mitigate soil erosion and stabilise shallow landslides. This study focuses on the long-term evolution of slope stability and multi-taxon biodiversity in a shallow landslide in Tuscany, Italy, restored in 1998 with SWBE techniques. The restoration followed the extreme weather event of 1996, that affected the Versilia region, where the landslide is located.

Field surveys conducted since 2013 examined vegetation succession, soil cohesion, and biodiversity complexity in the restored area. Root system analyses of dominant species, including chestnut (*Castanea sativa* Mill.), alder (*Alnus glutinosa* L.), and hornbeam (*Carpinus betulus* L.), provided insights into root reinforcement and soil cohesion. Slope stabilisation analysis, using SSAP 2010™ freeware to model different temporal scenarios of the study site, demonstrates improvements in slope stability over time. In 2024, multi-taxonomic monitoring was conducted, considering 3 bio-indicators: plants (arboreal, shrubs and herbaceous components), soil microorganisms, and insects. Field survey analyses were carried out at three study sites: (1) a SWBE-restored landslide, (2) a naturally evolved landslide, and (3) a controlled landslide with minimal anthropic disturbance. All sites share comparable characteristics (e.g., slope, exposure, surrounding vegetation, and soil type). Field survey data highlighted different biodiversity dynamics across the three study sites.

The restored landslide exhibits higher alpha-diversity among herbaceous species and a well-structured canopy, indicative of a maturing ecosystem. Beta-diversity analyses revealed differences in soil microorganism and insect community compositions compared to unmanaged or minimally disturbed landslides. Our findings underscore the ecological and technical benefits of SWBE techniques, which ensure slope stability over time but enhance quantitative biodiversity. Multi-taxon diversity monitoring in shallow landslide restoration provides insights into the ecological effectiveness of nature-based solutions in degraded environments. Further interdisciplinary research on the effects of different SWBE techniques on ecological restoration is needed to emphasise their potential to merge geotechnical stability with long-term biodiversity gains.

POSTER

Role of relative root radius in pore structure and root morphology via *in-situ* x-ray CT imaging

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Understanding soil–root interactions is essential for elucidating the dynamics of root morphology and pore structure, thereby promoting nature-based solutions for the stability of geotechnical infrastructures. Employing *in-situ* plant growing and X-ray computed tomography (CT) imaging (**Figs. 1a** and **1b**), along with an innovative multiscale CT image-based analysis (CT-IBA) workflow, we analysed how root growth influenced soil pore structure and root morphology (**Fig. 1c**), along with the temporospatial evolution of the local porosity surrounding individual roots. Our findings indicated that specimens with larger glass beads exhibited reduced porosity variation, attributed to their larger pore spaces accommodating finer barley roots. The increased physical impedance of these larger beads likely restricted root-induced alterations in pore structure. In contrast, maize specimens displayed greater variability in porosity changes compared to barley, particularly in finer media, whilst barley showed a more consistent trend of increasing porosity over time, especially in coarser substrates. These findings underscored the significant dualistic impacts of soil–root interactions on soil pore structure and root morphology. Furthermore, our results identified four distinct patterns of local porosity changes, influenced by the spatial arrangement and chronological progression of root growth, emphasising the importance of both temporal and spatial factors in soil–root interactions. Finally, the preliminary validation of our hypothesis suggested that the relative root radius (*RRR*) serves as a quantitative metric for these interactions, linking root characteristics to changes in pore structure. A conceptual model was developed to relate soil–root interactions—specifically pore-clogging and particle reorganisation—to *RRR*, identifying three interaction types that significantly affect local porosity and root morphology. The findings revealed that relatively fine roots (*RRR* significantly less than one) tended to induce substantial pore clogging, whilst coarser roots (*RRR* near or greater than one) facilitated the formation of new pore spaces, highlighting the dual role of root systems in modifying soil structure. This research not only elucidated the complex interplay between root growth and soil pore structure but also enhanced our understanding of the hydromechanical properties of rooted soils.

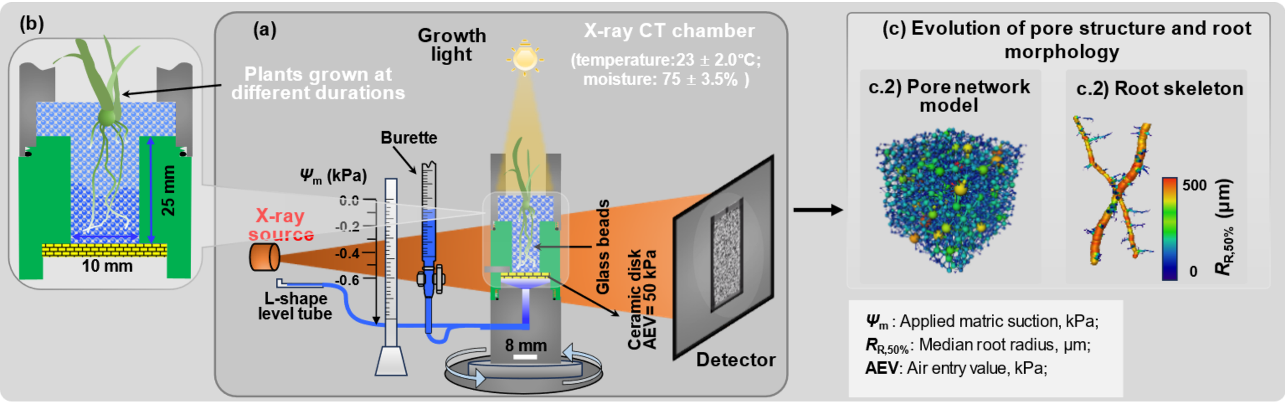

Fig. 1 *In-situ* plant growing and CT scanning. (**a**) CT chamber, where plant roots were grown and CT scanned; (**b**) A rooted soil specimen; (**c**) Evolution of pore structure and root morphology using (**c.1**) pore network model and (**c.2**) root skeleton.

POSTER

Palisades on ravine erosion control in degraded area in northeastern Brazil

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Linear erosion is explained by rills, ravines, and gullies. To mitigate erosion processes in ravines, soil bioengineering techniques are used, as low-cost and highly efficient alternatives. In this case, materials from living plants are demanded in association with inert materials, in the implementation of biotechniques to stabilize slopes, through drains, geotextiles, or through physical barriers such as palisades. The objective of this work was to evaluate the sedimentation promoted by the use of palisades on the erosion control in a degraded area. The research was carried out at the Rural Campus Experimental Station, of the Universidade Federal de Sergipe, located in the municipality of São Cristóvão – SE (10°55'S latitude and 37°11'W longitude), northeastern Brazil (Figure 1). Several palisades were built with bamboo logs (*Bambusa vulgaris*) in a ravines, where sediment input of three of them was monitored (Figure 2a,b,c and d), as well as erosion process from 2023 to 2025, with monthly data collection. Rainfall data were also collected to better understand the dynamics of the erosion process.

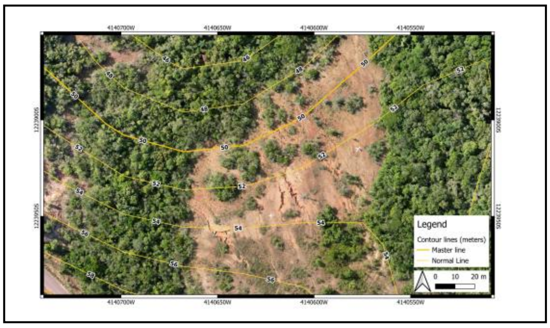
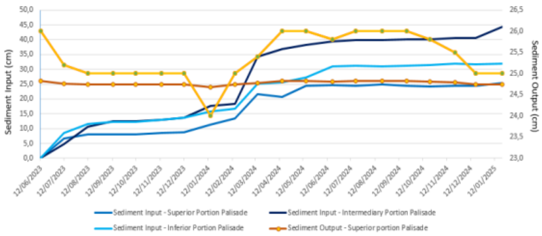


Figure 1. Image of the studied eroded

Figure 2.a-Ravine, b-Palisades construction, c-Built Palisade, d- Palisade Monitoring.

The sedimentation in this area can be explained by several reasons. Initially by the occurrence of a argiluvic and petroplintic Plintosol, highly cohesive, with a low infiltration rate, deforested and degraded, in area of 4 to 11% slope. In this landscape there is a favorable environment to a faster sediment transport. Figure 3 illustrates an evolution of sedimentation totally linked to rainfall regime, highlighting the greatest period of sediment production in the rainiest months that go from March to July, falling significantly, when rainfall begins to decrease in the period from August to February.

Figure 3. Sedimentation behavior in the experimental area.



Ravines are potentially sediment-producing erosion processes, most often because they have already reached a level of degradation that makes their recovery difficult. Palisades, in turn, are efficient in controlling floodwaters, enhancing the recovery of the degraded area.

POSTER

The Effects of Arbuscular Mycorrhizal Fungi on Grass Establishment and Aggregate Stability in Compacted Soil

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Arbuscular mycorrhizal (AM) fungi play a vital role in plant stress relief and soil aggregate formation, which are crucial for improving ecological restoration on slopes. This study aims at enhancing the understanding of the interactions between AM fungi and grass species in compacted soil and their effects aggregate stabilisation. In a pot-culture experiment (Fig. 1), vetiver (*Chrysopogon zizanioides*) and Bermuda grass (Cynodon dactylon) were planted in compacted decomposed granitic soil, with and without inoculation of arbuscular mycorrhizal (AM) fungi. Additional treatments included Bermuda grass, inoculated or not, in uncompacted loose soil, resulting in a total of six treatments. In each pot, the root zone and hyphae zone were separated using a mid 38- m mesh. After twenty weeks, plant biomass and root traits, AM fungal colonization and hyphae length density, soil organic matter, and aggregate stability were determined.

Our findings demonstrate that AM fungi significantly improved overall growth of vetiver grass in compacted soil and Bermuda grass in loose soil (Fig. 2). While Bermuda grass root development was reduced in compacted soil compared to loose soil, aboveground growth remained unaffected due to the support of hyphal network. This indicates the potential of AM fungi in promoting ecological restoration efforts on slopes. The influence of these changes on soil aggregate stability will be discussed during the conference.

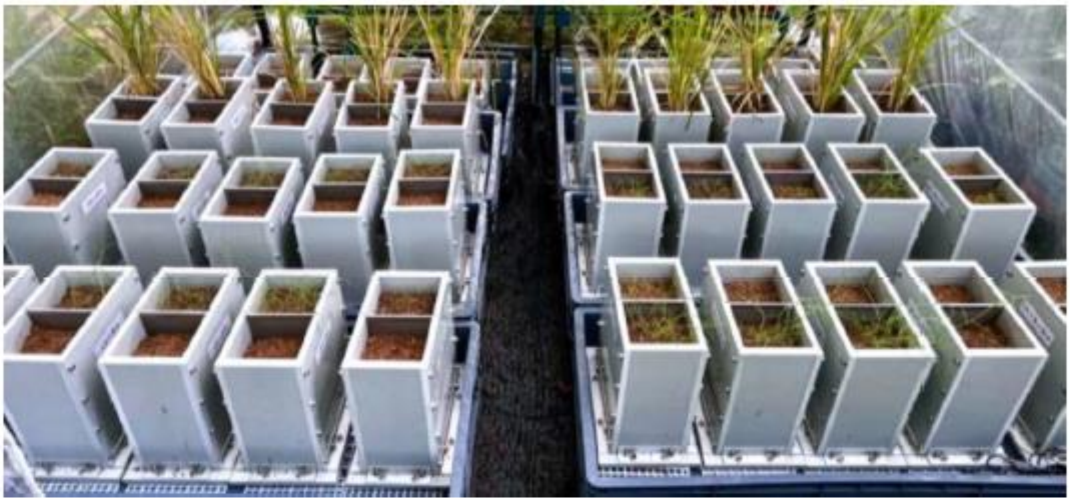

Fig 1. Experiment setup

POSTER

How small is not too small? An investigation of the scale effect on root–soil mechanical interaction

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Geotechnical centrifuge modelling technique has been increasingly used to investigate root–soil mechanical interaction for vegetation-related problems such as tree stability and anchorage under wind. This technique tests a reduced-scale (by a scale factor, N) physical model (3D-printed root analogue in this study) under a much more controlled conditions in the laboratory than in the field. These Nth-scaled root analogues are tested at an elevated Earth's gravity (g) condition by N times, so the soil mechanical behaviour, which is stress dependent, can be correctly modelled and the soil–structure interaction tested would be representative to the prototype. However, while the size of the root analogue can be scaled by N times, the soil particles are normally not scaled by the same N due to practical difficulties; this leads to a fundamental question: how small is not too small for the reduced-scale root analogue to avoid from any so-called particle size (or scale) effect? Excessively reducing the dimension of the root analogues would violate the condition of soil continuum, making the mobilised soil stress-strain behaviour not representative to the prototype. This study aims to investigate the scale effect on root–soil mechanical interaction by a technique called 'modelling of models'. In this technique, 3D-printed root analogues of four different scales (N = 20, 30, 40 and 50) (**Fig. 1a**) were buried in the same soil type (i.e. the same particle size distribution) and then subject to the same lateral push-over at four different g-levels (**Fig. 1b**) ; hence these four physical models represented the same prototype. Each tree root was monotonically pushed to a rotation of 40^{o} and the mobilised bending moment in these models were measured. The results show that the lateral roots extended along the loading direction and the tap root played the most significant role in the anchorage resistance against lateral push-over. We also found that the scale effect would overestimate the overturning moment capacity when the ratio of the weighted average root diameter to the mean soil particle size (d_{ave}/D_{50}) was less than 6. It is evident that the scale effect vanished when d_{ave}/D_{50} reduced to 3.6 for the anchorage resistance (moment capacity and rotational stiffness) at rotations smaller than 0.2^{o}, a value that is normally used in non-destructive push-over tests in the field.

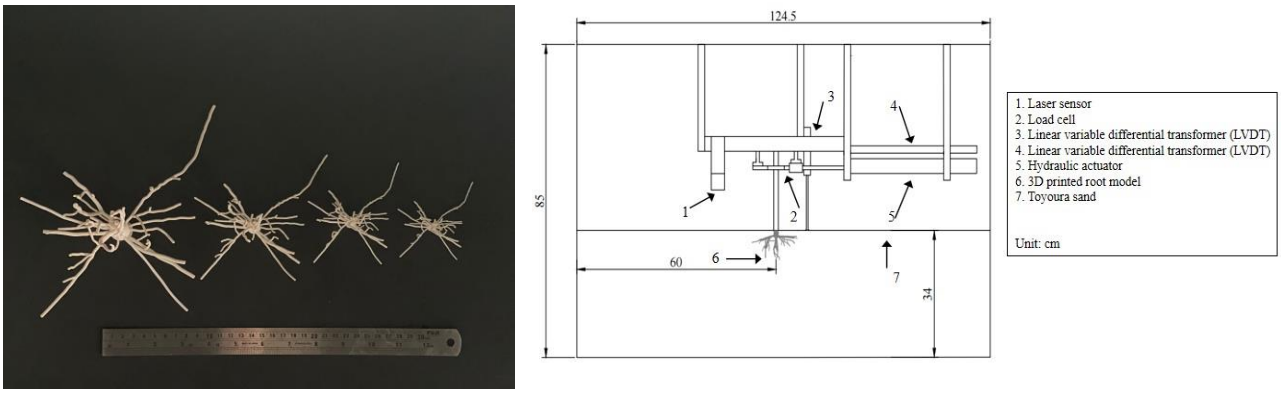

Fig. 1 (**a**) 3D printed root models under different scale factors; (**b**) Elevation view of centrifuge model package.

POSTER

Exploring the relationship between saturated hydraulic conductivity (Ks) and roots distribution

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Soil hydraulic conductivity and root distribution represent two important parameters towards the engineering applications, ranging from quantification of hydrological and geotechnical processes (e.g., water runoff, shallow landslides) to agricultural management and forestry practices. To investigate the relationship among these soil parameters, two study areas located in Italy (Garfagnana, Tuscany) and Switzerland (Zollikofen, Bern) were selected. RAR (Root Area Ratio) and Ks (Saturated Soil Permeability) data were collected through the application of the trench method and the field infiltration measurements (Aardwark permeameter), respectively. Results indicate that RAR concentrates in the first soil layers and decreases sharply following deeper layers. RAR and Ks show positive linear correlation that depends on the soil and forest conditions. These results support the hypothesis that the presence of roots represent a key factor in preferential infiltration and, therefore, hydrological models applied for the runoff modelling, slope stability and soil erosion can be improved considering the spatial distribution of roots derived by field measurements and/or remote sensing data.

Keywords: Root Distribution, Soil Saturated Permeability, Ecological Engineering, Field Methods, Water Infiltration in Forest Soils.

POSTER

The landslide on September 28, 2021, on the southern slope of Cerro El Sarnoso in the municipality of Jiutepec, Morelos.

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On September 28, 2021, on the southern flank of Cerro el Sarnoso in the municipality of Jiutepec, Morelos, a rotational landslide occurred. It has a horseshoe shaped main crown open to the south, with a length of 270 m. Its highest point is located at 1508 m a.s.l., and presents three secondary scarps with lengths of 124, 159, and 193 m, respectively. The axis of the landslide is directed toward S20°E, and its flanks are parallel to this direction (Morales Barrera, 2021). The dimensions of the landslide involve an area of approximately 3.2 ha. We determined three danger zones: very high, high, and medium.

The landslide destroyed 19 houses located within the slide mass (very high danger zone), resulting in their total loss. The High Danger Zone, a potentially sliding mass, include 24 houses, while the Medium Danger Zone 30 houses. Similarly, the landslide destroyed streets, roads, and infrastructure.
Not all the residents of the Vista Hermosa neighborhood were affected. 73 homes experienced either total or partial damage, affecting 440 people.

The primary natural trigger factor was the extraordinary rains that occurred during the season. The anthropogenic factor that also has contributed to the landslide, is the extraction of material at the base of the slope, with an estimated volume of 16,740,581 m^3 of material removed. This level of extraction provoked a lack of support at its base, and consequently, the loss of stability in the upper mass. The extraction of material at the base of the slope is still active using explosives, and no actions have been taken to reduce the hazard. If we consider that intense rains are one of the main trigger factor, the future scenario is not encouraging, as it could reactivate suddenly and even have a greater mass displacement than on September 28, 2021.

This potential for increased mass displacement, points out the need for immediate intervention strategies to mitigate the risks associated with ongoing extraction activities. Without immediate actions, communities in the area could face catastrophic consequences if another significant rainfall occurred. Considering the characteristics and dynamic of Cerro El Sarnoso landslide, and the high risk that represents to the inhabitants of the Vista Hermosa neighborhood, we conclude that the best decision to reduce the risk would be the relocation of the affected families, since it represents a better cost benefit to the community, the government and the environment (Morales-Barrera, 2024)

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POSTER

Developing Nature-based Solutions in the Alps: *ex* and *in-situ* experiment to select willows for subalpine soil and water bioengineering structures

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Soil and Water Bioengineering techniques are a sustainable alternative to civil engineering and grey infrastructure to prevent erosion processes that threaten streambank stability. These techniques are not yet developed and documented in subalpine streams, where climatic and hydrological conditions are particularly challenging. It is well known that the success and integration of a SWBE technique is best achieved when it is possible to use indigenous plant material. However, the biotechnical characteristics of specific subalpine shrub willows are nearly unknown. The unique information comes from empirical and not detailed results showing a low survival rate of cuttings. However, studies showed that they can play a full role in stabilising the banks of high-elevation streams. We conducted *ex-situ* and *in-situ* experiments to assess the biotechnical traits of cutting capacity of species present at high-elevation to improve SWBE on these streambanks.

- *Ex situ*

Three species of subalpine shrub willow with poor information on their survival and any on their growth were chosen: *S. caesia*, *S. foetida* and *S. hastata*. *S. purpurea*, known for its cutting ability in lowland streambanks, was used as a control species. The cuttings were placed in growth chambers for 4 months under controlled conditions of light, humidity, and temperature. We tested the effect of a growth hormone, with the assumption that it would stimulate willow growth. 50 cuttings per species were planted (25 with hormone treatment). At the end, we measured root diameter, primary root number, root biomass, cumulated shoot length, shoot number and, shoot biomass.

The survival rate was high for the four species (>96%). The hormonal treatment had no significant effect on growth. *S. hastata* was distinguished by its very high biomass and *S. purpurea* by its very long structure.

- *In situ*

Six species were selected: three subalpine shrub species (*S. caesia, S. foetida, S. hastata*) and three tree species (*S. daphnoides, S. myrsinifolia, S. purpurea*). The cuttings were planted in sand at 2 100 m a.s.l.. 50 cuttings per species were planted in October 2022. In September 2023 and 2024, at the end of the vegetative periods, the survival rate and the cuttings' growth were assessed: aerial and belowground biomass and cumulative shoot length.

The survival rates were excellent, 100% for *S. caesia*, *S. foetida* and *S. purpurea* and over 88% for the other three species the first year and the second year over 85% for the six species. Both years, tree species had grown faster than shrub species. Between the first and second growing seasons, growth was multiplied by a factor of 3 to 4.

The six species can play distinct roles in protecting the streambank, such as stabilizing the surface and increasing soil cohesion, and they complement one another. Depending on site conditions, we recommend using these species in combination. These findings have significant implications for the successful installation of cuttings in SWBE structures in subalpine environments. All six species seem to be suitable for SWBE projects in mountainous regions.

POSTER

Geology Influences Surface-Water Availability and Vegetation Patterns on Santa Rosa Island, Channel Islands National, Park, California, USA

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Landscapes with heterogeneous geology and rock permeability may drive groundwater and surface-water availability that strongly influences the spatial distribution of vegetation types. To better understand spatial correlations between discontinuous occurrences of surface water and an endangered, endemic plant species *Castilleja mollis* (soft-leaved island paintbrush), we compared mapped geology, surface-water presence, and vegetation on Santa Rosa Island, Channel Islands National Park, U.S.A. Historically subject to pronounced, long-term landscape disturbance by grazing ungulates, the island is currently managed for ecosystem health and low-impact recreation.

To explain correlations between geology and surface-water map patterns, we measured in situ permeability of geologic units with a handheld air permeameter (NER TinyPerm II). Measurements were taken during low-flow conditions, under ambient moisture conditions, at the outcrop scale. Sites represent a range of surface-water conditions and mapped geologic features such as rock type or structure, including unit contacts and faults. At faults, we measured permeability within fault cores, damage zones, and adjacent undeformed rock protolith. Permeability estimates at 31 sites (>600 measurements) reveal four trends associated with rock type and structure consistent with presence or absence of surface water: i) Volcanic rocks and intact, indurated sandstones and shales express lower to intermediate permeabilities ($\sim10^{-1}$–10^{2} mD), correlating with more spatially continuous surface-water presence. ii) Similar rocks with secondary fractures induced by tectonic or topographic stresses express intermediate to higher permeabilities ($\sim10^{3}$–10^{6} mD) and typically had no surface water present. iii) Fault zones may act as both conduits and barriers to flow, with clay-rich cores exhibiting low permeability ($\sim10^{-1}$–10^{2} mD) whereas adjacent damage zones contain broken rock with intermediate to higher permeabilities ($\sim10^{2}$–10^{7} mD). Outside of damage zones, non-fractured rock protoliths generally have lower permeabilities ($\sim10^{0}$–10^{3} mD). If clay-rich cores are laterally continuous, such effective barriers to cross-fault flow would locally force groundwater to the surface as observed along some fault traces. iv) Bedding, parting, and fracture planes appear to impart local anisotropy as reflected in observed increased permeability in directions parallel to such planes.

To compare geology, topography, *C. mollis* presence, and hybrid *Castilleja* species distributions, we surveyed plants as points along eight transects, 50-m wide and 600-m long, near coastal bluffs. Surficial geologic map polygons describing unit age, process of deposition, and texture were used to represent local substrates. Associated topographic derivatives were obtained from airborne lidar. Correlations between the input data of geologic and vegetation mapping, elevation, aspect, and topographic convergence were analysed at 12.5-m spatial resolution using a binomial logistic regression model related to plant presence. Preliminary model results indicate that geology is by far the most explanatory predictor for the distribution of *C. mollis*. Twenty geologic units, ranging in age from Tertiary to Holocene, were present in the transect area. Those units most associated with the presence of *C. mollis* were limited to hillslope colluvium over Tertiary rock and Quaternary eolian sand and silt deposits. Such sediments tend to be somewhat mobile, hydrologically well drained, and may contain higher salinity and carbonate on the windward island side.

These relations highlight how mapped geology and associated material properties can inform necessary inputs for robust modelling of hydrologic conditions and habitat types in the context of passive recovery and active restoration of native vegetation populations.

POSTER

Vegetation and soil formation heterogeneity in the *Pinus hartwegii* treeline ecotone in two mountains in México

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Pinus hartwegii is the highest altitude growing pine species in the world and forms the treeline in Mexico. Due to its adaptations to high altitude environmental conditions, this species has been proposed as a tree with a great capacity to promote the accumulation of organic matter and form fertile soil in cold and inhospitable environments. Little is known about the influence of *P. hartwegii* and treeline vegetation on soil formation. In this study, we evaluated the influence of *P. hartwegii* and treeline vegetation on this process. To this end, we described vegetation characteristics and the macro and micromorphological properties of soil profiles in the treeline ecotone at sites with and without direct influence of the *P. hartwegii* canopy on two Mexican mountains (Fig. 1). Our preliminary results indicate a clear influence of *P. hartwegii* on soil formation, promoting the presence of surface organic horizons (O, A) in sites beneath its canopy. In sites outside the canopy, where grasses (*Festuca tolucensis*) dominate, the AC horizon predominate. The micromorphological characteristics of the soils and the influence of the remaining vegetation (herbaceous) are still being determined. Understanding the influence of *P. hartwegii* on soil genesis at the treeline can provide important insights into primary plant succession in environments such as high tropical mountains and into the biotechnological potential of this species.

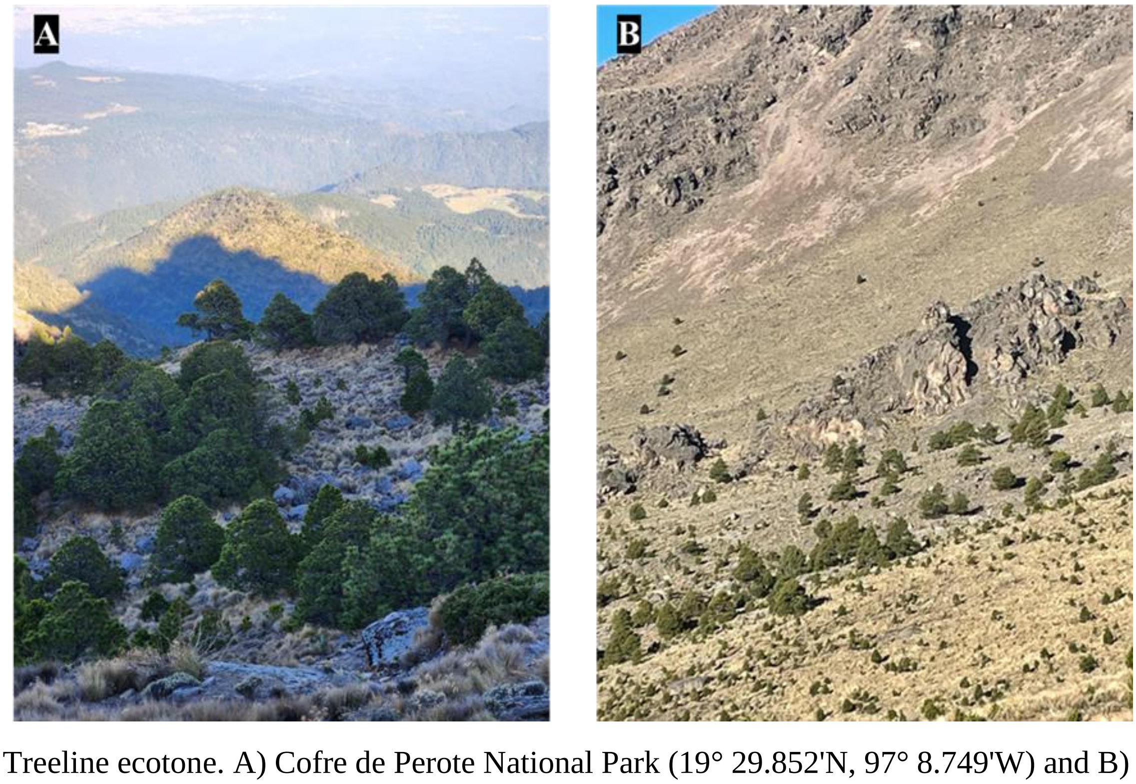

Fig. 1. Treeline ecotone. A) Cofre de Perote National Park (19° 29.852'N, 97° 8.749'W) and B) Pico de Orizaba National Park (19° 0.558'N, 97° 15.307'W) (Images credits: Perroni, 2025).

POSTER

Numerical Analysis of Spatial Distribution of Root System Architecture on Slope Stability

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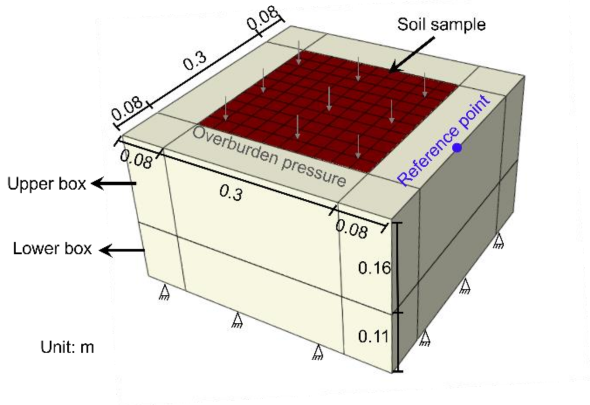
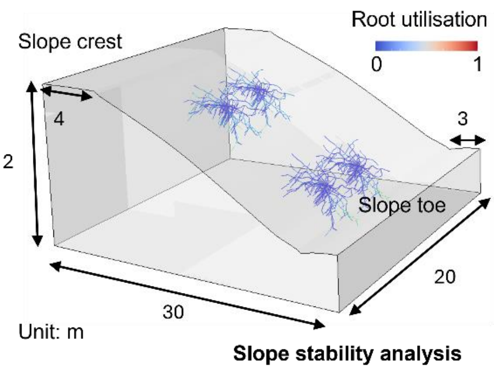
Root systems, anchored shallowly beneath the ground, enhance slope stability by mobilising both root–soil interfacial properties and root mechanical strength. Accurately quantifying this root reinforcement is essential for evaluating slope stability, as the interaction between roots and soil plays a critical role in resisting slope failures. Numerical modelling offers a powerful tool to investigate root–soil mechanical interactions, enabling virtual simulations of pull-out and shear tests informed by prior known root architectures, which are often difficult to observe directly in the field. However, modelling root reinforcement remains a significant challenge due to the highly complex interfacial interactions between individual roots and the surrounding soil. Previous studies have commonly simplified root reinforcement by approximating root contributions as an additional cohesion term (i.e. root cohesion) incorporated into soil strength criteria. While this approach has gained popularity, it fails to capture the mobilisation of internal root stresses and cannot adequately explain the mechanisms behind root–soil load transfer. In this study, a novel three-dimensional finite element (FE) model is proposed to address these challenges. A dynamic root growth model will be employed to generate realistic root system architectures while root-soil interaction will be simulated using a point-to-point frictional contact algorithm within a continuum mechanics framework. Using this FE model, the contribution of roots to soil strength will be quantified at the single root system scale through simulated direct/simple shear tests (Fig. 1(a)), allowing detailed analysis of root strength mobilisation. Subsequently, the model will be extended to the slope scale, simulating multiple interacting root systems to assess their collective reinforcement effects and investigating the influence of root spatial distribution on slope stability (Fig. 1(b)). This approach aims to provide new insights into the role of root reinforcement in slope stability, offering an improved understanding of root–soil interactions from the scale of individual root systems to entire slopes.





(a) (b)

Figure 1. FE model of (a) laboratory direct shear tests and (b) rooted slope stability analysis