INVESTIGATION OF THE INTERACTION OF A CLAYEY SOIL COVER WITH VEGETATION AND THE ATMOSPHERE

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Abstract

The use of novel naturalistic interventions making use of selected vegetation have been already proven to be successful in the reduction of erosion along sloping grounds, or in increasing the stability of the shallow covers of slopes, whereas the suitability of vegetation as slope stabilization measure still needs to be scientifically verified for slopes location of deep landslides, whose current activity is weather-induced, as is often the case in the south-eastern Italian Apennines. In this contribution, preliminary field data representing the interaction of clayey soils with a selected vegetation species are presented and discussed. These have been logged within a full scale in-situ test site, where the deep-rooted crop spices have been seeded and farmed. The test site, being approximative 2000 m2, has been set up in the toe area of the weather-induced Pisciolo landslide. The impact of the vegetation on the soil state is examined in terms of the spatial and temporal variation of the soil water content and suction from ground level down to depth, both inside and outside the vegetated test site.

1. Introduction

The contribution of vegetation within the soil-vegetation-atmosphere (SVA) interaction is one of the bio-engineering issues most discussed in the literature (Lu et al., 2020; Guo et al., 2020). With the aim to give a contribution in defining the role of the vegetation within the SVA interaction, this work specifically focuses on the effects that the vegetation cover has on the hydraulic regime in the slope, which influences the stability of potential landslide bodies of depth from small to large. Among other vegetation-induced effects, the crop has been seen able to reduce the rainfall water infiltration rate (Ng et al., 2013; Leung et al., 2015). Moreover, selected deep-rooted crops can impact even strongly the hydrological balance at the ground surface, by increasing water interception and runoff, which on the whole, cause a reduced net infiltration rate. At the same time, such vegetation can ensure a deeper and more intense water uptake, by means of their deep root system (Ehlers et al., 1991), reducing the pore water pressure even at depth and, hence, increasing the effective stresses which in turn increases also the soil shear strength available in the slope (Fredlund et al., 2012). Therefore, such selected vegetation may help in providing mitigation to deep weather-induced landsliding.

This contribution reports monitoring results of SVA interaction with reference to an in-situ test showing the impact of selected deep-rooted vegetation. To this aim, the monitoring data are discussed accounting for the basic features of the SVA interaction, i.e., accounting for the specific behaviour of the type of plant grown on the slope and the specific hydro-mechanical properties of the clay material.

2. The test site: objectives and general description

The test site has been set up in the toe area of the Pisciolo mechanism, being a roto-translational multiple landslide, found to be triggered by seasonal weather-induced fluctuations of the pore water pressures at large depth (Cotecchia et al., 2014, 2019). The green quadrangular reported in Figure 1a and 1b represents the test site area (about 2000 m^2), where selected deep-rooted crops were seeded, whereas spontaneous sparse vegetation covers irregularly the surrounding part of the slope; a full and detailed description of the test site has been reported by Tagarelli & Cotecchia (2022). At the test site, ten indigenous different plant types were selected and seeded, being either the Gramineae or the Leguminosae (Tagarelli & Cotecchia, 2022), by the Italian company “PratiArmati” with the aim to study suitability of the vegetation to increase and maintain the soil suction above the water table and to reduce the piezometric heads at depth (i.e. hydrological soil reinforcement, Lu et al., 2020).

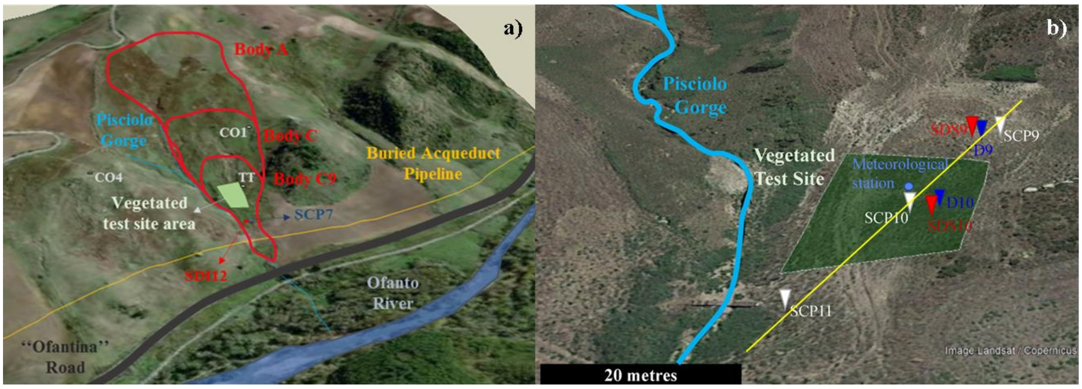

Fig 1. Aerial 3D view of the Pisciolo landslide and of the test site (a). The landslide bodies A, C and C9 (red lines) are reported with the trace of the aqueduct pipeline (yellow line) and the vegetated site area (light green). 3D view of the test site area, together with all the installed instrumentations as described in the text (b).

A hydro-mechanical characterization of the soil cover has been carried out, in order to evaluate the composition, state, hydraulic and mechanical properties of the soils set in interaction with the crop. Furthermore, a set of instruments was installed, both inside and outside the vegetated area to monitor both the climate and the soil state down to 7 m depth, inside and outside the on-purpose vegetated area (Fig. 1b). The monitoring data, of use for a phenomenological characterization of SVA interaction, are discussed in the following, after the presentation of all the tools installed within the test site area.

Five boreholes were excavated at the test site area (Fig. 1b), namely SCP9, SCP10, SCP11, SDS9 and SDS10. Three boreholes were continuously cored (SCP9, SCP10, SCP11) and two were drilled by destructive coring (SDS9, SDS10). One electric piezometric cell was installed at the bottom (i.e., 7 metres b.g.l.) of each continuous coring borehole, while water potential probes (MPS-6) were installed at different depths into the destructive boreholes. The water potential monitoring verticals (i.e., SDS9 and SDS10) were placed very close to the boreholes equipped with the piezometers. Besides the piezometers and the suction probes, also two plastic tubes were installed down to 1.6 m depth into the slope (i.e., D9, D10 in Figure 1b), being of use to measure water content profiles with depth with a capacitive probe. In particular, the D10 vertical was setup to carry out the monitoring of the water content inside the seeded area, whereas the D9 vertical was excavated outside the seeded area. Moreover, the weather has been monitored by means of a meteorological station (i.e., Davis Vantage Pro 2) placed within the test area at a 2 m height above ground level.

Several disturbed and undisturbed soil samples were taken during the drilling stages to assess the physical composition properties of the soil cover as well as their hydro-mechanical properties (Tagarelli & Cotecchia, 2022). Grading curves and Atterberg’s limit determinations, together with the analysis of the continuous cores have allowed for the reconstruction of the lithological setup of the test site area, mainly characterized by a highly plastic and inorganic silty clay with sand, with high water retentive properties and relatively low saturated permeability values (Tagarelli & Cotecchia, 2022), interbedding fractured rock blocks and coarser strata, found during the coring of the three boreholes.

3. Soil-vegetation-atmosphere interaction monitoring

Figure 2 gives a comprehensive representation of the variation of the soil state with time, through the different seasons, in terms of water content and suction profiles, by making a comparison between the monitoring vertical representative of the effect of the selected deep-rooted vegetation (D10-SDS10) and the one which is representative of the effect of the spontaneous vegetation (D9-SDS9). All the monitoring data, logged from the beginning of 2018 on, have been plotted with reference to the belonging season. Soil water content measurements were measured with depth up to 1,6m with 10 spacing, with reference to both the Veg and NoVeg condition; such monitoring data have been plotted to reconstruct profiles of the water content with depth. Only with reference to the NoVeg condition, water content data measured in the laboratory on soil specimen sampled at the site were available at different depths. Good coherence is found between the laboratory determinations and the in-situ measurements by means of the capacitive probe, which gives confidence on the quality of the in-situ measurements. Moreover, suction values have been measured with time also at 1m and 2,5m depth along both the Veg and NoVeg verticals, SDS10 and SDS9, respectively. Suction values at 1m depth have been then used to build the in-situ SWRC for both the Veg and NoVeg condition, shown in Figure 3, which, reports the monitoring data with reference to the Veg and the NoVeg conditions, as green dots and brown dots, respectively. The fitting has been carried out by adopting the van Genuchten model, resulting in the fitted Veg and NoVeg water retention curves (Figure 3).

In this context, the roots appear to make the clayey material less retentive than the undisturbed one (i.e., NoVeg), by possibly modifying its meso-structure with a mechanism of aggregate cracking as recognized likely to happen in several cases by Lu et al., 2020. In particular, the roots action on the material appears on one hand to move the AEV only slightly backwards, and on the other hand causes the retention curve to become more steeper than the curve fitted on data of the undisturbed condition (Figure 3). The quality and the significance of the water retention in-situ monitoring are testified by good coherence existing between the NoVeg monitoring data and fitting curve with other determinations of water retention data in the laboratory along both drying and wetting paths (herein not reported). However, what is interesting to note from Figure 3 is that the direction towards which the roots make the retention curve of the material to change, is then confirmed also by the laboratory determinations of the retention properties. Indeed, Veg and NoVeg soil specimens, collected from the soil cover at 0,3m depth, have shown retention properties consistent with those monitored in situ (Figure 3). However, it can be recognized that the intensity of the root-induced modifications on the retention states has been found to be much less in the laboratory than that identified in situ. Furthermore, it appears also that the roots may impact on the hysteretic behaviour of the material; indeed, it is easy to notice that the hysteretic behaviour is nearly vanished for the Veg condition (full and empty green crosses in Figure 3), whereas the hysteresis is clear with respect to the NoVeg condition (full and empty brown crosses in Figure 3).

By making use of the fitted soil water retention curves for both the Veg and NoVeg conditions, the water content profiles with depth may be then traduced in suction profiles with depth (Figure 2), which may be then compared with the monitored suction data for both the Veg and NoVeg condition.

In autumn, winter and beginning of spring, representative of the “wet” periods, it is found that the water content profiles characterizing the Veg condition appear to be lower on average than those logged along the NoVeg monitoring vertical, certifying the role of the vegetation in reducing the water content in the soil; however, the vegetation is believed to act both in reducing the amount of water infiltrating the ground surface, thank to the rainfall interception, and in increasing the transpiration flux, which with time allow for a reduction of the water content with depth. Indeed, it is found that the variation with time of the water content along the Veg vertical appears to be much stronger in a soil stratum up to approximately 1,3m depth, where it is then believed the roots are able to take water from the soil for the transpiration process. Unfortunately, such hypothesis is not yet supported by measurements of the depth of the root system; however, either direct (i.e. excavation of a trench and direct observation) or undirect (i.e. geoelectrical surveys) will be soon carried out. In correspondence to the water content values, the suction profiles are coherent with what reported so far, and those are also quite well matching the suction data logged by means of the water potential probes at 1m depth.

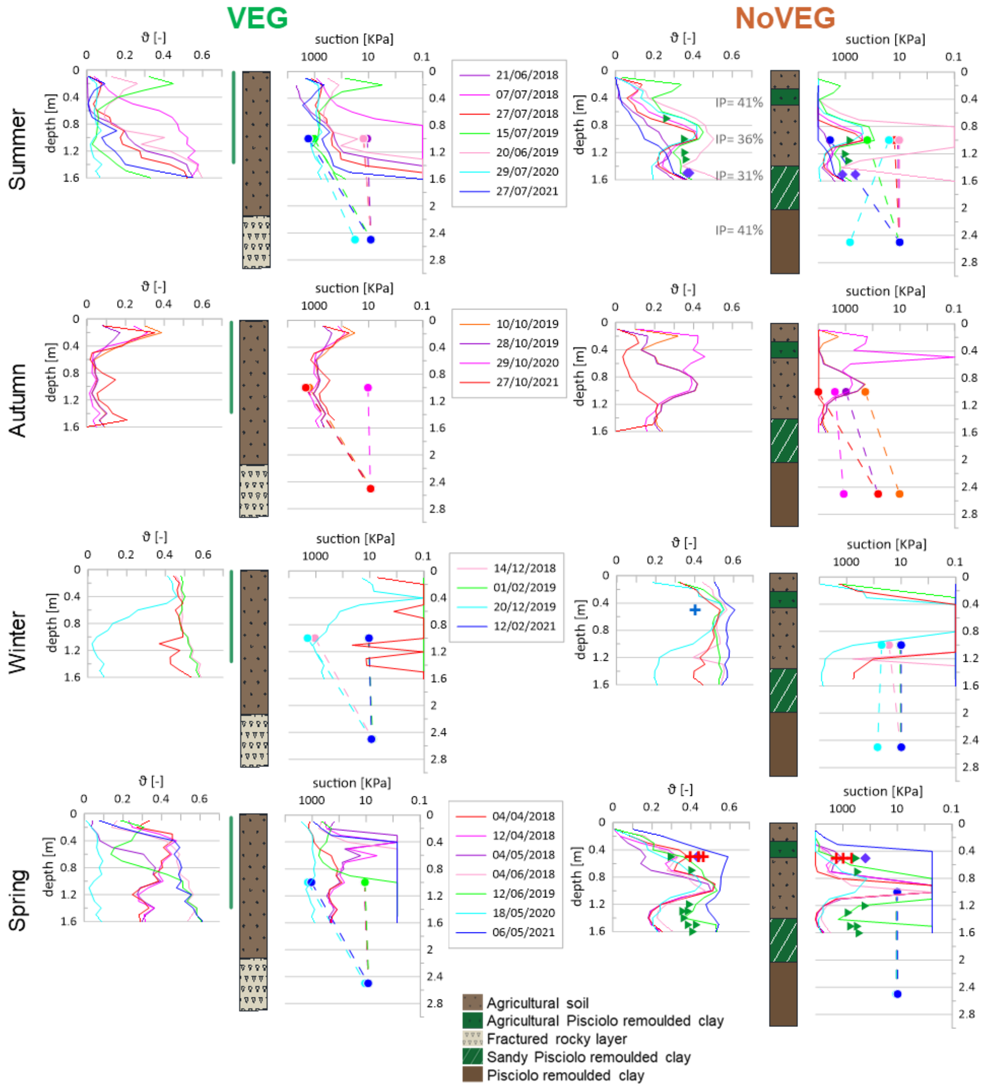

Figure 2. Volumetric water content profiles with depth along vertical D10 (Veg) and D9 (NoVeg), together with the corresponding pore water pressure profiles with depth computed from the retention curves (Fig. 4) and the suction values monitored over time at 1 and 2.5m b.g.l..

During summer, the impact of the vegetation is less evident, and measured water contents appear to be similar to those of the NoVeg area. This may be due to the high gradients of evaporation induced by the solar radiation during summer, in association with the effects of desiccation cracking, allowing to deepen the impact of the weather; all this results in low water contents also in the NoVeg area which are close to the ones in the Veg area, where the vegetation crop protects the soil underneath which experiences lower temperatures if compared to the NoVeg area (shadowing effect), circumstance confirmed to occur in-situ, even if herein no temperature data have been reported; a discussion on this effect has been extensively reported by Tagarelli & Cotecchia (2022).

On overall it can be said that the vegetation appears to be able not only to keep quite high suction values during the year, and correspondingly low values of the water content, but also to guarantee a sort of disconnection between the weather forcing actions and the soil state at depth in the cover. However, it is worth noting that the suction values reached in the Veg area are on overall lower to those characterizing the NoVeg area even by one order of magnitude; this circumstance happens despite the water contents in the Veg area are lower than those outside (NoVeg), and is connected to the modifications that the root system has caused on the SWRC as already described. As such, very high suctions have been found to occur in the NoVeg area, even at 2,5m depth, where also values higher than 1000 kPa have been measured. However, this would not be beneficial, if a mitigation of the water infiltrating the ground surface is of purpose, since at high suctions usually relevant desiccation cracks occur, which on the whole increases a lot the potential infiltration rate.

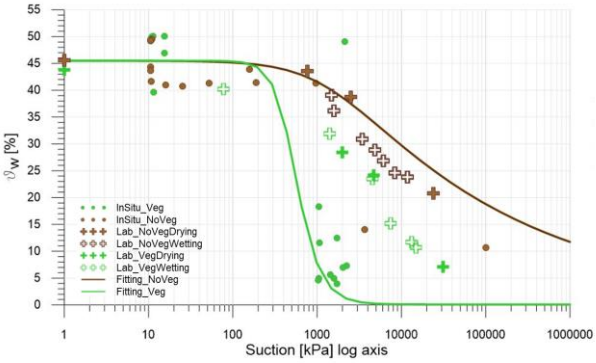

Figure 3. In-situ soil water retention behaviour of the soil cover layer with reference to the Veg (i.e., green dots) and the NoVeg (i.e., brown dots) conditions, together with the corresponding van Genuchten fitting curves, in comparison with the corresponding water retention data determined in the laboratory (drying and wetting data).

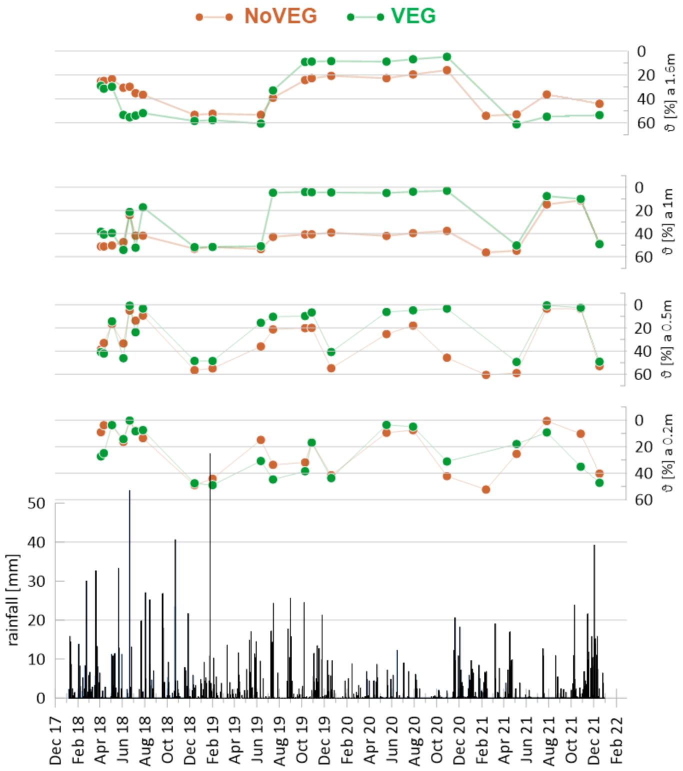

Fig 4. Values of the measured volumetric water content at different depths (i.e. at 0,2m, 0,5m, 1m, 1,6m) with time reported for both the verticals D10 (Veg) and D9 (NoVeg) in correspondence with the daily rainfall.

Figure 4 reports about the water content with time at different depths (i.e. at 0,2m, 0,5m, 1m, 1,6m) with time reported for both the verticals D10 (Veg) and D9 (NoVeg). As expected, the water content variations are seen to resent to the rainfall with different timing. Longer time spans were needed for the soil to resent of the rainfall-induced wetting path at depth. Moreover, a certain effect on both the water content values and its variations with time are found, when considering Veg and NoVeg data. During wetting, the water content values of the Veg condition seem higher than that of the NoVeg one, whereas, during dry period, when evapo-traspiration is acting the most, is vice versa. The reason may be found in the interplay existing between the root and the soil, in association with the water content measure technique adopted in situ. In particular, the different volumetric behaviour of the roots and the soil plays a relevant role during both wetting and drying path, so that it is likely that micro void may appear between the roots and the soil when desaturation occurs. Hence it is possible that the volume of soil with reference to which the capacitive probe measures the water content, is containing also empty voids (i.e. air), which lower the overall recorded water content. On the contrary, during wetting phases the water content of the Veg soil may result higher than those of the NoVeg condition, due to the higher moisture content of the roots, which increases the overall recorded water content value.

4. Conclusion

The interaction between the soil, the vegetation and the atmosphere consists of a very complex set of physical and chemical phenomena involving also a living entities (i.e., the vegetation), which has not been yet fully studied and schematized; however, the scientific research community has already taken several steps toward a full understanding of such phenomena. With the purpose to deepen the knowledge and trying to verify if selected deep-rooted vegetation may be suitable as a nature-based solution for the landslide risk mitigation, a real scale test site has been set up in a weather-induced landslide mechanism. This experience represents a reliable test of how the selected vegetation may behave in the field, without any laboratory-like conditionings.

To conclude, the preliminary data herein reported show that the selected deep-rooted vegetation adopted is able to impact on the SVA interaction in a not negligible way, encouraging the research programme to be further carried out in determining if and how this technique may be of use as a landslide remediation measure for such wheatear-induced mechanism.

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