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Investigation on changes in the retention behaviour of a sand due to Vetiver roots

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ABSTRACT: Vegetation can significantly influence the soil hydraulic properties, prompting extensive research into the use of plant roots as a functional tool for enhancing the performance of geotechnical systems. The present study investigates the potential evolution of the water retention ability of a sand as influenced by the presence of a Vetiver plant after one growing season. The methodology involves comparing the hydraulic retention properties of undisturbed sand with those of sand with roots. To simulate the soil-vegetation interaction in the laboratory, a physical model replicating a vegetated backfill has been developed. It consists of a tank with a geosynthetic draining side, filled with siliceous sand, in which a Vetiver plant has been grown. The setup includes tensiometers positioned at different depths, enabling continuous suction measurement during a controlled rainfall test. Measurements have been carried out on specimens to determine the hydraulic properties of the sand unrooted, for implementing them in numerical simulation of an infiltration process through soil without vegetation. Then, the comparison between the suction values predicted by numerical simulation and those recorded during the physical model test provided indications of the influence of roots on the soil hydraulic properties.

Keywords: retention behaviour of rooted sand; physical modelling backfill; WRC of siliceous sand

1 INTRODUCTION

In recent years, increasing attention has been paid to the role of vegetation as a sustainable tool from the perspective of improving geotechnical systems, promoting the development of bioengineered systems.

Among the various plant species investigated, Vetiver grass (*Chrysopogon zizanioides* (L.) Roberty) has emerged as one of the most effective for bioengineering techniques, such as slope stabilisation and soil erosion control (Chandnani, 2025; Mahima, 2025), due to its dense, extensive, bushy root network.

The present research investigates the changes in the retention behaviour of a siliceous sand induced by the growth of Vetiver roots over one growing season. A physical model reproducing a vegetated backfill was developed and equipped with mini-tensiometers to continuously monitor suction during a controlled rainfall test. Element-scale tests were conducted to determine the saturated hydraulic conductivity and the water retention curve (WRC) of the unrooted sand, which would be a benchmark for the interpretation of the physical modelling results. This paper presents the experimental setup, testing methodology, and preliminary findings of the ongoing investigation. The results aim to contribute to a better understanding of the hydraulic role of vegetation in sandy soils and to support the development of bioengineered systems.

2 MATERIALS AND METHODS

2.1 Materials

A three-year-old Vetiver, supplied by Vetiver Toscana (MS, Italy), was used to recreate the vegetation cover in the backfill model.

A washed, dried, and sterilised sand from the Po River (Italy) was selected for its high content in Silica (SiO_2), which supports Vetiver roots development, and for its uniformity (SP according to USCS) that would enable a relatively consistent void ratio profile with depth. Moreover, this soil is typically employed as backfill in retaining structures. The grain size distribution was conducted according to ASTM D 1369-4 Standard, in wet mode, and is reported in Figure 1. The specific gravity was measured as Gs = 2.68, with a Helium gas pycnometer (ASTM D5550) at the University of Perugia.

Finally, a layer of drainage geocomposite (GCD) was employed as a drain for the backfill.

2.2 Experimental setup

A physical model was built in the laboratory to reproduce soil–root interaction in a vegetated backfill. The tank used in the model, which serves as a test container, is a prototype (1.10m x 0.5m x 0.5m) designed by Federico et al. (2019) (Figure 2a). It is provided

with one vertical, transparent Plexiglass side and a perforated base to ensure the drainage of the system.



Figure 2. a) Tank for physical model; b) Drainage geocomposite placed in contact with transparent side; c) Phase of filling with soil; d) Transplanting of Vetiver grass; e) View of the physical model

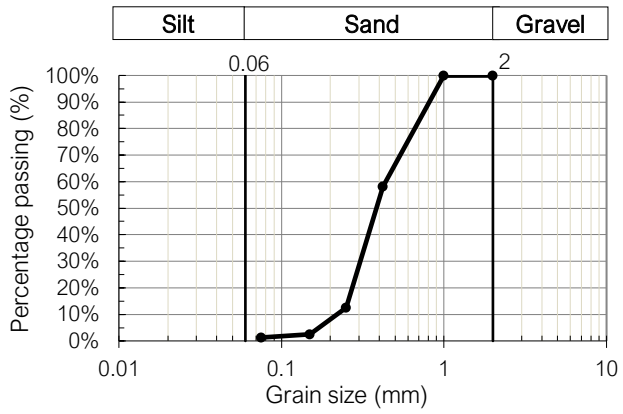


Figure 1. Grain size distribution of the selected soil

One side of the tank features three housings for holding three mini-tensiometers, supplied by Soilmoisture Equipment, operating within the 0–100 kPa matric suction range, aligned along the vertical axis at 750 mm (ch1), 500 mm (ch2), and 250 mm (ch3), from the base. A sheet of drainage geocomposite was placed in contact with the transparent side of the tank to facilitate continuous visual inspection of

the GCD's integrity (e.g., root intrusion, clogging from soil particles) (Figure 2b).

The tank was filled with the previously described sand (figure 2c), having a relatively low initial water content (w_i = 0.28%).

The sand was pluviated in successive layers to create a self-weight compacted material, initially occupying a volume of 0.238 m^3. Table 1 reports the specific gravity Gs (ASTM D5550), and the average initial state of the soil, i.e. gravimetric water content w_i (ASTM D2216), and, derived from phase relationship, dry unit weight γ_{di}, void ratio, e_i, saturation degree, S_{ri}, and initial volumetric water content θ_i.

Table 1. Soil average initial state

Gs	w_i (%)	γ_{di} (kN/m^3)	e_i	n_i	S_{ri} (%)	θ_i
2.68	0.28	13.33	0.97	0.49	0.77	0.0038

The sand was wetted to be prepared for transplanting the Vetiver grass (Figure 2d). The model was placed in the geotechnical laboratory under controlled humidity and temperature. To support plant growth, an artificial LED light was installed above the plant (Figure 2e). The plant was grown from February 2025, with irrigation applied as needed. After a growing period of 8 months, the sand experienced a slight settlement in the testing box, due to wetting and drying cycles. This corresponded to a new average void ratio of e_0 = 0.908 and a dry unit weight of γ_d = 13.75 kN/m^3.

As anticipated previously, the investigation of the soil unrooted was carried out by means of element testing.

Direct measurements of the saturated hydraulic conductivity (k_s) of the unrooted soil used in the physical model were carried out at a representative volume scale. The test employed a permeameter derived from a modified oedometer (Bottiglieri, 2012). A specimen of the tested sand was reconstituted by pluviation inside the apparatus. The resulting dry unit weight was similar to that obtained in the physical model as effect of wetting-induced collapse resulting from irrigation throughout the plant growing season.

Before testing, the specimen underwent 24 hours of saturation, and then permeability tests were performed using the constant-head method.

The WRC of the unrooted sand was measured using an experimental device designed by Bottiglieri et al. (2021). It consists of a transparent perspex cylindrical cell, with ports on the lateral surface for the insertion of two mini-tensiometers, which provide the direct measurement of the matrix suction.

The sand was placed into the apparatus by pluviation and was compacted to a density similar to that attained in the physical model after the plant-growth period. The WRC was determined along the wetting path by adding predetermined amounts of distilled water at each step, increasing the volumetric water content, from $\theta_r = 0.0038$ (practically "residual") to $\theta_s = 0.476$ (saturated). Tensiometers' readings of matrix suction were taken at each water increment step.

2.3 Test procedure

The test on the physical model involves an artificial rainfall designed to investigate the hydraulic response of the soil in the presence of roots, particularly the changes in soil retention capacity compared to that of the soil without roots.

A numerical analysis (using Hydrus 2D) was conducted to obtain an initial insight into the infiltration dynamics. The analysis was implemented using the hydraulic functions obtained from the characterisation of the unrooted sand, to predict the suction profile evolution expected for the soil without roots, i.e., to perform a "baseline" prediction. This baseline was compared with the suction profiles recorded during the rainfall test to assess the influence of roots on the transient seepage.

In this simulation, GCD was modelled as a seepage face, and atmospheric boundary conditions were applied to the soil surface, with pluviometric data assigned as time-variable boundary conditions. The other surfaces were set to no flux.

On this basis, the infiltration experiment was then performed. A preset volume of water was supplied through a system of drippers designed to simulate rainfall uniformly over the top of the model. The water drained through GCD was collected and measured to allow for a water balance. The minitensiometers installed in their housings continuously recorded matric suction during the event, capturing the arrival of the wetting front.

The data obtained from the experiment will subsequently be used in an inverse analysis, to be performed using Hydrus-2D (Levenberg–Marquardt algorithm), in order to characterise the whole rooted soil layer as a homogeneous equivalent system.

3 PRELIMINARY RESULTS

The unrooted sand was characterised at the element scale (k_s and WRC) to deduce the parameters to be implemented in the numerical analysis mentioned above.

A permeability test was carried out on the unrooted sand after 24h of saturation, when a slight initial settlement of the specimen (0.07 mm) was observed, resulting in a small change in void ratio. In fact, the specimen's thickness remained constant throughout the tests. The saturated hydraulic conductivity was estimated as $k_s = 4.38 \times 10^{-6}$ m/s, representative of the confinement of the sand at the base of the model.
The water retention curve of the unrooted sand, measured along a wetting path as illustrated in section 2.2, is shown in Figure 3. The figure presents both the experimental data points and the corresponding fitting function, whose parameters are reported in Table 2. No appreciable volume change was observed in the specimen during the test. The interpolation was performed according to the van Genuchten formulation using the RETC code (van Genuchten et al., 1991).

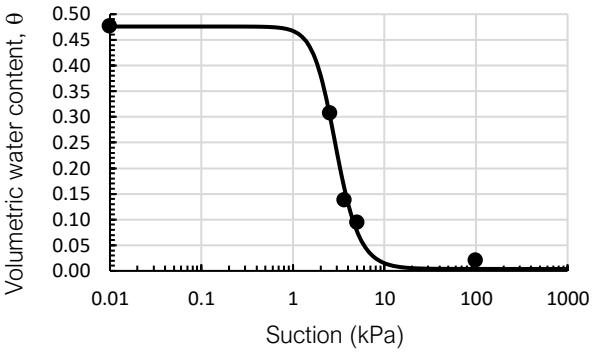


Figure 3: Water retention curve of unrooted sand

Table 2. Interpolation parameters of the unrooted sand WRC

θ_r	θ_s	α (kPa^{-1})	n	m=1-1/n
0.0038	0.476	0.392	3.80	0.74

The rainfall employed in the numerical simulation lasted approximately two hours (7200s), with a rainfall intensity of the order of 10^{-5} m/s.

Figure 4 shows the evolution over time of matric suction obtained numerically, at the three observation points Ob1, Ob2, and Ob3, which correspond to the positions of the tensiometers in the physical model Ch1, Ch2, and Ch3. The wetting front reaches Ob1 first, approximately 2000s after rainfall starts; Ob2 responds after 5800s, while Ob3 remains unreached throughout the test, indicating that the wetting front did not extend to that depth within the considered time frame. The same infiltration rate was then imposed as rainfall intensity duration in the physical model test.

As previously said, the suction profiles recorded were compared with the corresponding dataset ob-

tained in the numerical analysis to evaluate the influence of vegetation on the hydraulic response of the sand.

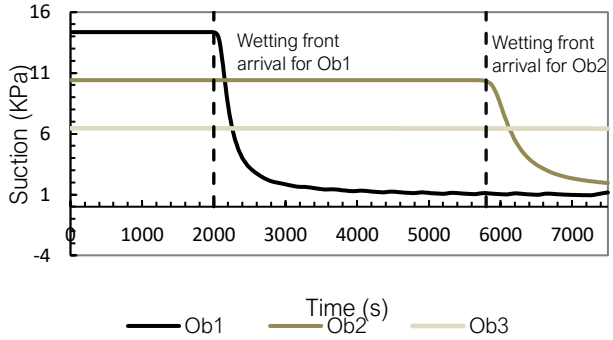


Figure 4: Evolution over time at observation nodes for an applied rainfall intensity

For example, Figure 5 shows the suction values vs. time logged at Channel 2, compared with those obtained from the numerical simulation (Ob2). The wetting front in the physical model arrives earlier at tensiometers Ch2 compared to the numerical prediction, giving evidence of the influence of roots on the sand hydraulic properties.

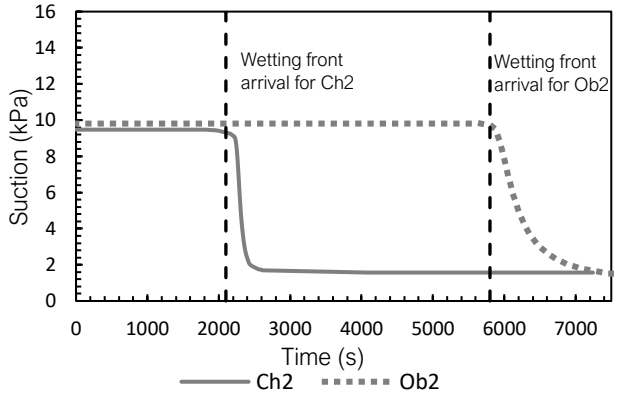


Figure 5. Suction values vs time logged at Channel 2 (Ch2), compared with the numerical prediction (Ob2)

4 CONCLUDING REMARKS

An experimental investigation was carried out at two different scales – physical model and element volume – to depict the hydraulic retention properties of a sand influenced by the presence of Vetiver roots after one growing season. The study described the setup of the physical model, simulating a vegetated backfill, developed to investigate the hydraulic behaviour of a rooted soil. The sand used in the model was characterised at the element scale, providing the parameters for a preliminary numerical analysis. The results, expressed as the transient regime of matric suction at three observation nodes at different depths, offer a valuable baseline for interpreting the physical model test. The infiltration test allowed continuous monitoring of matric suction at different depths, providing insight into the advance of the wetting front within the rooted soil.

The comparison between physical modelling results and numerical simulation of the infiltration process suggests a change in the hydraulic properties of the sand, related to the deepening growth of roots. After one growing season, the roots seem to have increased the sand permeability, probably due to preferential flow paths they created. The data obtained during the infiltration test will be employed to perform an inverse numerical analysis to derive the hydraulic functions and characterise the whole rooted soil layer as a homogeneous equivalent system.

Future work will focus on the physical model as a long-term experiment, enabling monitoring of the system's hydraulic performance history as the root network evolves through the sand.

5 ACKNOWLEDGEMENTS

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