

# DELINEATING THE DYNAMIC INTERACTION OF VEGETATION AND SOIL PROPERTIES IN CONTROLLING CUT SLOPE SOIL EROSION

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**Abstract.** The exposed environment of the cut slope due to insufficient coverage and changes in soil properties is greatly accelerating the occurrence of soil erosion. While revegetation is an alternative tool to mitigate soil erosion and provide a long-term solution for slope stability problems; the integration of vegetation and soil properties into slope erosion control, remains a challenge due to variation in plant types and site-specific slope conditions. Thus, in this study, three experimental plots were set up on the eroded cut slope: bare (control), less dense, and dense. To evaluate the interaction between vegetation and soil properties in mitigating soil erosion, the vegetated plots were grown with potential pioneers, namely *Lantana camara*, *Melastoma malabathricum*, and *Bauhinia purpurea*. After a two-year observation, the dense plot recorded the highest increment in soil total porosity and hydraulic conductivity by 45.8% and 73.8%, respectively, thus enhancing the infiltration capacity of the slope soil and reducing the erosion rate between 10 to 15 t h<sup>-1</sup> year<sup>-1</sup>. Furthermore, *L. camara* in dense plot recorded the highest plant growth performance, followed by *M. malabathricum*, and this verifies their potential as good slope pioneers. Meanwhile, porosity, fungal/bacterial ratio, respiration, organic matter, and shoot hydraulic conductance were identified as significant parameters relevant to control erosion. In conclusion, the positive vegetation-soil interaction has shed light on slope stability, plant productivity, and most importantly erosion resistance.

**Keywords:** *slope stability, soil loss, vegetation cover, slope revegetation, vegetation-soil interaction*

## Introduction

The cutting of slope faces to facilitate infrastructure development such as foundation and highway construction has resulted the exposure of rock surfaces to the weathering process and soil formation. As a result of ineffective maintenance and protection, the balance of soil hydrological networks is severely disturbed, and this leads to poor soil structure and susceptibility to soil erosion and slope failure. Moreover, hydrological and geotechnical processes within this degraded slope landscape is a serious concern as they depend on climate and geological conditions, topography, hydro-geotechnical properties, permeable interfaces, the type of surface cover, and human intervention (Huat et al., 2008; Sorbino and Nicotera, 2013; Rahman and Mapjabil, 2017).

Furthermore, due to high seasonal precipitation in tropical regions, the oversupply of water flow into slope soils during intense or prolonged rainfall may overwhelm the soil infiltration rate, and this decreases the matrix suction and soil shear strength in addition to causing surface flow due to saturation excess (Ismail et al., 2018; Zhen-li, 2016). Consequently, these effects would further imperil the hydrological system of the slope, anticipating the increase in erosion and slope instability (Tang et al., 2018).

As one of the important slope management practices, revegetation is a feasible approach to ameliorating the function of the soil-plant complex system and improving slope stability. In general, the contributions of vegetation in enhancing slope stability and resilience can be divided into mechanical and hydrological. Firstly, through mechanical reinforcement, the vegetation root systems may increase the soil shear strength by root anchorage to improve cohesion, while the root architecture provides high resistance to prevent soil movement (Pollen, 2007; White et al., 2013; Saifuddin and Osman, 2014; Leung et al., 2018). Secondly, hydrological reinforcement through transpiration-induced matric is also deemed essential for slope hydrology and stability (Garg et al., 2015; Smethurst et al., 2015).

Notwithstanding, in some cases, vegetation on the slope can be detrimental to stability since its mere presence does not directly translate to the significant mitigation of slope problems. Since each slope has its own geological condition, the factors influencing slope stability can be very complex and require individual attention. For example, vegetation provides better volumetric retention compared to the bare slope; however, the physical properties and depth of the soil may exhibit greater influence than vegetation (VanWoert et al., 2005). Although vegetation can lower the soil moisture via interception and evapotranspiration (Halim and Normaniza, 2015; Keim and Skaugset, 2003), the effects might be adverse and subject to increase soil infiltration and permeability during intense rainfall (Coppin and Richards, 1990). Therefore, the consideration of specific plant types/species for the slope area has become a great emphasis in line with revegetation efforts.

Native species are the best candidates for the potential long-term solution towards stability and restoration; however, not all species are suitable for this practice. Furthermore, previous studies have also revealed that the practice of monoculture system, which focuses on the desirable characteristics of a single species, had caused soil depletion, expedited soil erosion, and adversely affected soil nutrient content (Moghaddam, 2014; Dislich et al., 2017). Hence, a mixed-culture system with high plant species is suggested as an alternative for slope revegetation management as it is more productive than monoculture (Zhang et al., 2012; Pretzsch and Schütze, 2016; Liu et al., 2018). The right combination of potential species can highly resist the harsh environment, maximize the soil nutrient cycling, increase carbon storage, and ultimately reduce the risks of soil erosion (Nerlich et al., 2013; Zhao et al., 2017).

In sum, the primary components of soil formation such as climate, parent material, and terrain landscape that compose the basic properties of soil are beyond the influence of management. Yet, biotic and abiotic factors are good targets of soil management, especially on the eroded cut slope area. Although vegetation on the cut slope sounds possible, it is a complex process and unfavourable soil conditions can make its introduction more challenging. Hence, the objectives of this study are to critically evaluate the interaction between vegetation and soil properties against soil erosion and to highlight the relevant parameters regulating slope processes at the plant-soil-atmosphere interface in the context of erosion occurrences.



dense (80% of plant coverage), each with 8 m x 8 m in size (Fig. 2; Table 1). These vegetation densities suitably allow for interception ( $\geq 95\%$ ) of the available Photosynthetically Active Radiation (PAR) for plant growth whilst promoting the establishment of new species (successors). Three potential slope plants were selected in this study, namely *Lantana camara*, *Melastoma malabathricum*, and *Bauhinia purpurea* (Halim and Normaniza, 2015; Saifuddin et al., 2016; Normaniza et al., 2018). These plants were transplanted onto slope using a Microclimate Plant Propagation Technique with modified soil depth (Osman and Barakbah, 2011) and they grew without any management practices throughout the experimental plots.



**Figure 2.** Experimental plots located on the third berm of the slope. From the left: bare plot (B), dense plot (D), and less dense plot (LD)

**Table 1.** Basic information on the studied plots

Plot	Slope angle (%)	Elevation (m)	Plant density (plant/m <sup>2</sup> )	Initial vegetative coverage (%)	Number of plants/species ratio ( <i>L. camara</i> : <i>M. malabathricum</i> : <i>B. purpurea</i> )
Control (C)	53	63.5	0	0	0
Less dense (LD)	55	64.1	0.5	50	32 – 11:10:11
Dense (D)	57	64.5	0.81	80	52 – 17:17:18

## Data measurement

### Soil properties

#### Laboratory analysis – total porosity, soil organic matter, and organic carbon

The soil samples in this study were collected using a metal auger (Edelman, Eijkelkamp, The Netherlands) up to 1 m in depth. Briefly, the soil samples were taken randomly from each plot with seven-point locations by traveling in a zigzag pattern, and they were taken every six months for two years. Meanwhile, the samples within the individual core sample were further homogenized by hand mixing, stored in polythene bags, and transported to the laboratory for processing. To determine the total porosity, the soil samples were then oven-dried at 105 °C for three days and calculated as follows:

$$\text{Total porosity (\%)} = 1 - \text{Bulk density} / \text{Particle density} \times 100 \quad (\text{Eq.1})$$

where particle density = 2.65 g cm<sup>-3</sup>.

$$\text{Bulk density} = \frac{\text{Oven-dry weight of soil (g)}}{\text{Volume of soil core (cm}^3\text{)}} \quad (\text{Eq.2})$$

While the soil organic matter was determined using the loss on ignition (LOI) method (Buurman et al., 1996), the total organic carbon, on the other hand, was determined using Walkley and Black's (1934) method.

#### *Field investigation – soil respiration, moisture content, and hydraulic conductivity*

To measure the respiration rate and moisture content, an *in-situ* measurement was randomly taken every six months for two years from each plot with seven-point locations by traveling in a zigzag pattern. The soil respiration rate was measured via the closed respiration chamber system (EGM-4CO<sub>2</sub>, PP Systems, USA), while the soil moisture content was measured using portable Delta-T soil moisture (HH2 Moisture Meter, Delta -T Devices Ltd., England) installed at a depth of 5 cm from the soil surface, both between 11:30 and 12:30.

On the other hand, three holes were cored at each plot with 1 m in depth and 11.5 cm in diameter for the measurement of soil hydraulic conductivity (K), which was performed using the Inverted Auger-Hole Method (Van Hoorn, 1979). This measurement was consistently taken during the third day after rain, between 11:30 and 12:30 with a PAR ranging from 1500-2100  $\mu\text{E m}^{-2} \text{s}^{-1}$ . Additionally, Gerlach's sampling field method (Gerlach, 1967) was also used to determine the soil erosion rate, and the experimental plots were further enclosed with wooden barriers about 25 cm in height in order to observe the influence of coverage treatment on soil loss. Finally, the eroded soils were collected, air-dried, and weighed accordingly.

#### *Soil microbe (fungal/bacteria ratio)*

The soil microbe enumeration of each treatment plot was analyzed every six months for two years and the soil samples were collected from seven-point locations by traveling in a zigzag pattern at the depths of 0-25 cm, 26-50 cm, and 51-100 cm using a sterile spatula. The samples were further mixed into homogenous samples, placed in sterile plastic containers, and transported to the laboratory for further processing. 1 g of soil was serially diluted ten-fold in quarter strength Ringer's solution, whereas 100  $\mu\text{l}$  of soil suspension was spread onto agar plates in triplicates. Bacteria and fungi were also isolated on soil extract agar and potato dextrose agar media, respectively. The inoculated nutrient agar plates were further incubated for 3 to 7 days at 28 °C, while the observed bacteria and fungi colonies were enumerated as colony-forming units per gram of soil (cfu/g).

#### **Vegetation measurement**

##### *Photosynthetic rate, transpiration rate, and leaf water potential*

Photosynthetic rate and transpiration rate were measured in three fully expanded leaves per plant with replicated three plants per species, per plot, and at a six-month interval. These parameters were measured using a portable photosynthesis system

(Li6400XT, LICOR, USA) in an open system mode, between 10:30 and 12:30. Ambient CO<sub>2</sub> (Ca) was set at 400 ppm, whereas the temperature and Photosynthetically Active Radiation (PAR) were set according to the ambience and ‘track PAR out’ in the leaf chamber, respectively.

#### *Root hydraulic conductance, shoot hydraulic conductance, and diurnal leaf water potential*

To avoid plant destruction and susceptibility to soil detachment, root (Kr) and shoot (Ks) hydraulic conductance were measured *in situ* for each species in both plots with a High-Pressure Flow Meter (HPFM) (Dynamax Inc., Houston, USA) after two years of observation. The measurements were taken between 11:30 and 12:30 at (PAR), ranging from 1500-2100  $\mu\text{E m}^{-2} \text{s}^{-1}$  and at ambient temperature in order to minimize the potential diurnal periodicity of hydraulic conductance (Tyree et al., 1995). Meanwhile, diurnal leaf water potential was measured using a Pressure Chamber (Model 1515D, PMS Instrument Company, USA) at 08:00, 10:00, 12:00, 14:00, 16:00, and 17:00, respectively.

#### *Statistical analysis*

A one-way analysis of variance (ANOVA) was performed to assess the effects of vegetation coverage on soil properties and plant physiological properties by using the SPSS software (Version 20, IBM, USA). While the estimation of control parameters that affects the variation in hydrological performance at different vegetation coverages was determined using linear mixed models (LMM) in R software. The ‘lme4’ package (Bates et al., 2015) was used to fit the model in R.

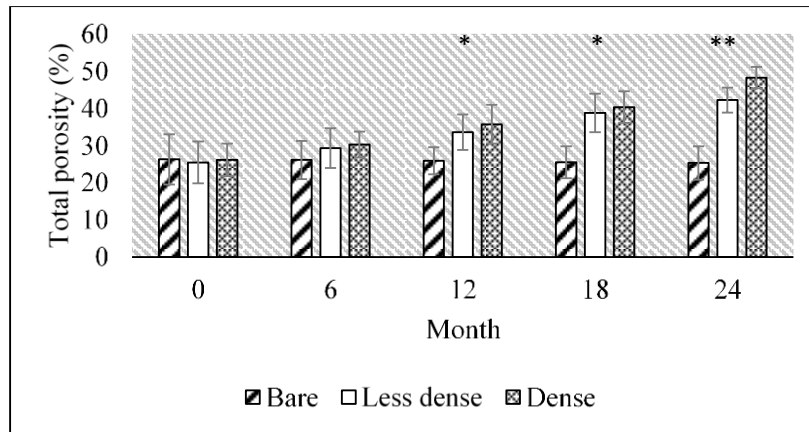
## **Results and discussion**

### *The influence of vegetation on soil structural stability*

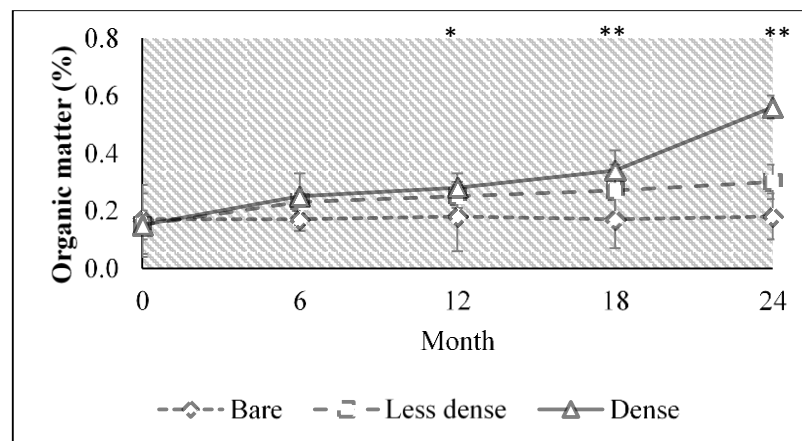
The dense plot (D) shows notable effects per the increase in total porosity by 45.8% in two years, which is significantly higher than the less dense (LD) and control (C) plots with 14.34% and 90.63%, respectively (*Fig. 3*). However, no increment of total porosity was found in bare soil (control plot). Furthermore, during the initial study period, the coarse and poorly structured sandy soil contributed to lower porosity, thereby resulting in poorly drained soil and lower soil ability to hold water (Libohova et al., 2018; Igor et al., 2020). After two years of revegetation, the higher vegetation coverage reduces the natural soil compaction and enhances the generation of macropores and channels by root penetration, thus improving the physical structure of the slope soil in order to resist erosion (Fageria and Stone, 2006).

As plants grow well, organic matter at the topsoil increases as well. In this study, organic matter content increased consistently with time in both revegetated plots. At the end of the experiment, organic matter content was drastically enhanced, and it further increased nearly fourfold as can be seen in the dense plot (D) (*Fig. 4*). The high number of plants in the dense plot (D) leads to a higher interception and high surface litter reserves and decomposition, thus providing a remarkable effect on the organic matter accumulation (Middleton, 2020). As a result, organic matter facilitates soil aggregation and subsequently conveys water more efficiently whilst enhancing soil infiltration (Yang and Zhang, 2011).





**Figure 3.** Means total porosity of the three experimental plots. Vertical bars indicate the standard deviation, whereas \* and \*\* denote significant differences between plots at  $p \leq 0.05$  and  $p \leq 0.001$ , respectively ( $n = 21$ )



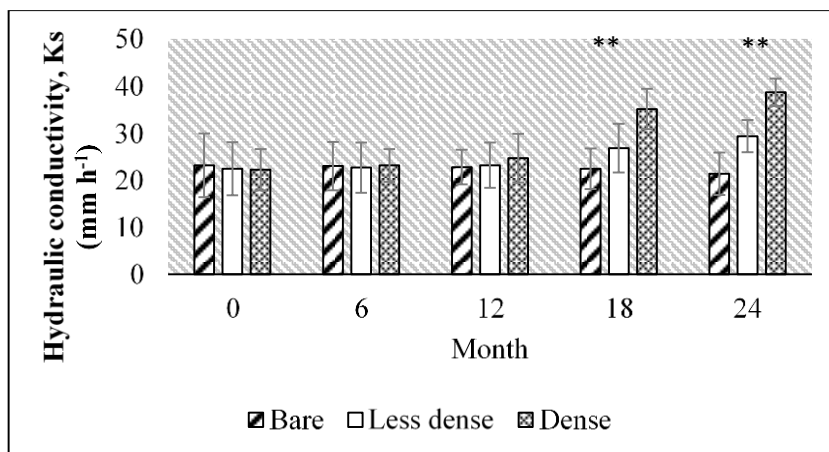
**Figure 4.** Means organic matter of the three experimental plots. Vertical bars indicate the standard deviation, whereas \* and \*\* denote significant differences between plots at  $p \leq 0.05$  and  $p \leq 0.001$ , respectively ( $n = 21$ )

### ***The contributions of vegetation to soil hydrological properties***

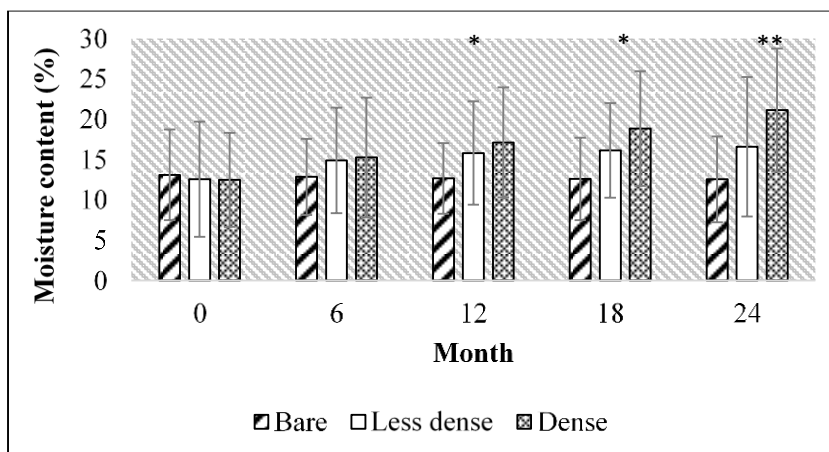
Within two years of observation, the soil hydraulic conductivity showed an increasing trend with vegetation coverage. While the dense plot (D) showed a positive increase in the hydraulic conductivity (Ks) value by 73.8% and followed by the less dense plot with 30.85% (Fig. 5), the control plot, however, demonstrated a fluctuation trend and it was slightly dropping towards the end of the experiment. Apart from organic matter accumulation, the plant roots may also enhance and promote soil hydraulic conductivity by forming pore networks, aiding in soil water conservation, and diminishing the slope runoffs (Wang et al., 2017; Lange et al., 2009; Neumann and Cardon, 2012; Kalhoro et al., 2017).

Furthermore, in terms of soil moisture, the dense plot (D) showed a higher value compared to less dense (LD) and control (C) plots with 27.44% and 68.37%, respectively (Fig. 6). Nevertheless, no changes were observed in the moisture content in all treatments during the 0, 6th, and 12th months. This suggests that the rainfall factor is

most influential than the slope pioneer effects. Additionally, the right vegetation density might have also influenced the higher moisture content in the dense (D) plot by reducing evaporative losses through plant canopy and holding both horizontal and vertical water flow in the soil via root distribution (Asbjornsen et al., 2011; Aalto et al., 2013). In fact, the presence of vegetation might likewise increase soil water consumption, and this was verified in this study as the findings demonstrated that soil moisture had further increased water consumption as opposed to the bare soil. Subsequently, this condition could avoid soil water stress and mitigate the impact of soil drying in the subsurface (Oliveira et al., 2005; Bayala and Prieto, 2019).



**Figure 5.** Means hydraulic conductivity of the three experimental plots. Vertical bars indicate the standard deviation, whereas \* and \*\* denote significant differences between plots at  $p \leq 0.05$  and  $p \leq 0.001$ , respectively ( $n = 9$ )



**Figure 6.** Means moisture content of the three experimental plots. Vertical bars indicate the standard deviation, whereas \* and \*\* denote significant differences between plots at  $p \leq 0.05$  and  $p \leq 0.001$ , respectively ( $n = 21$ )

### ***The impact of vegetation on soil carbon sequestration and quality***

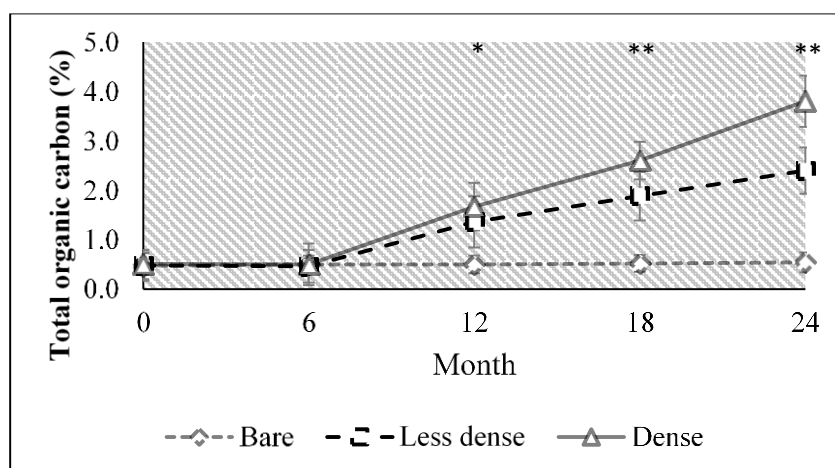
The results exhibited significant differences in the total organic carbon between treatments (Fig. 7). Evidently, both vegetated plots have significantly higher total



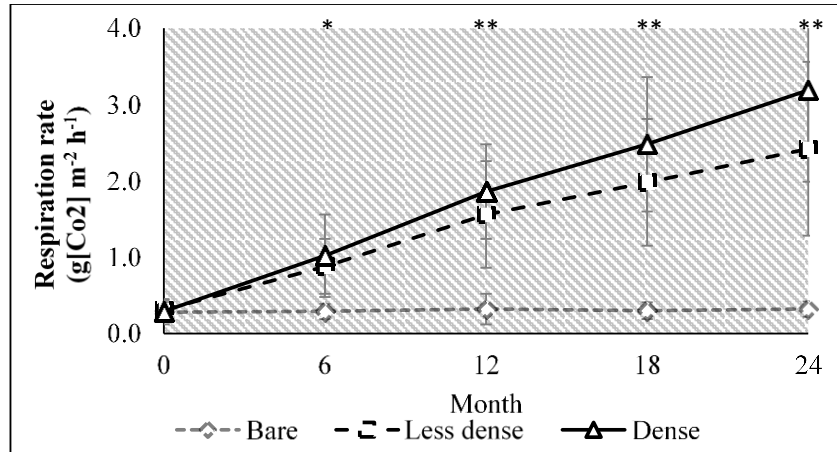
organic carbon than the control plot; hence, this improves the soil fertility of the slope. The total organic carbon value was also estimated to increase six-fold within two years in the dense plot (D) and four-fold (400%) in the less dense plot (LD). These findings suggest that high litter decomposition corresponds to a high concentration of organic carbon, thus accelerating the transport of organic carbon to deep soil layers and increasing soil carbon stocks (Dawud et al., 2016; Zhao et al., 2019). Besides, the mixed-culture system in this study had also produced a higher quantity and quality of litters, resulting in a remarkable soil carbon stock in the study area.

Due to high organic carbon concentration, the soil respiration rate was greater than during the early study period (Fig. 8). The increased respiration rate in the dense plot (D) was more than twice compared to 6 months after transplanting (212.75%), while the less dense plot (LD) recorded about 175% increment. The increase in the respiration rate might be due to decomposition activities of plant litters; hence, this shows a good sign of microbial abundance in soil and the development of the C cycle in terrestrial ecosystems (Adachi et al., 2006).

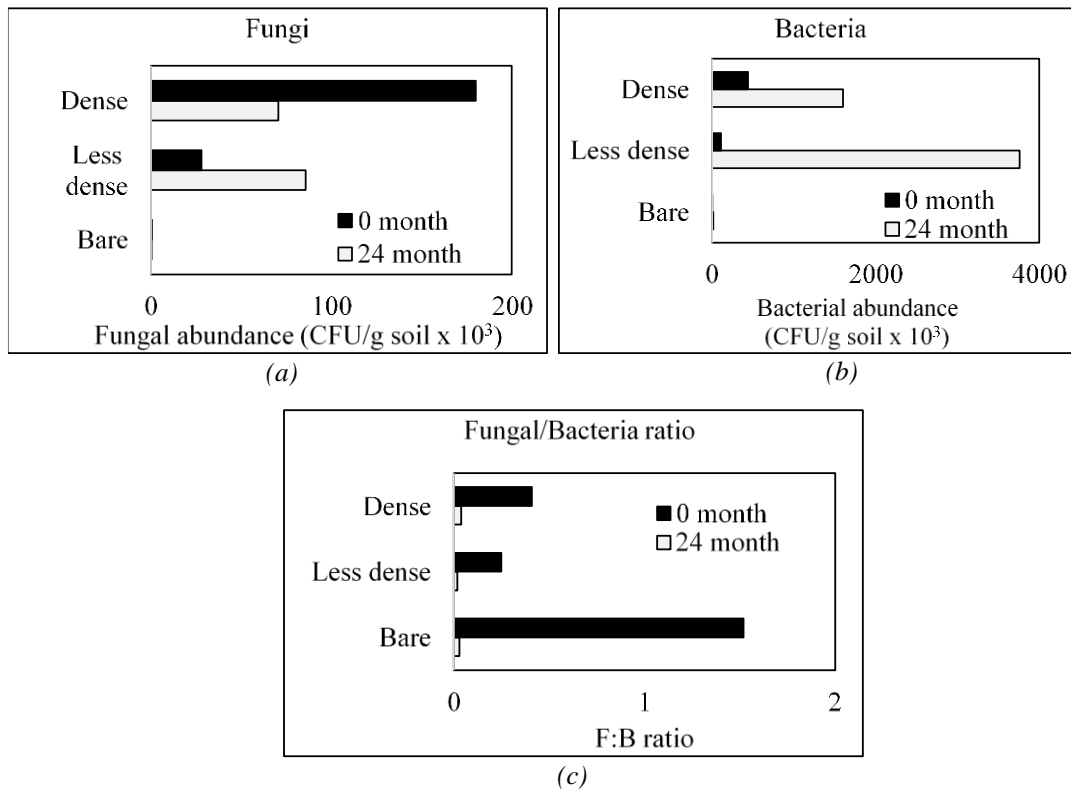
Overall, the initial datasets of both fungal and bacterial abundances were inconsistent between all treatments; thus, the F/B ratio fluctuated likewise. As illustrated in Figure 9, fungal and bacterial abundances as well as the F/B ratio were affected by vegetation establishment. After two years of observation, the F/B ratio tremendously decreased in all treatments, and the dense plot (D) exhibited a higher F/B ratio value compared to control (C) and less dense (LD) plots with 33.33% and 100%, respectively. Generally, the F/B ratio has been extensively used in soil ecology, particularly in the context of land management (Strickland and Rousk, 2010). While the cause of the differences in the F/B ratio in the studied plots is not entirely clear, they might be attributed to subtle differences in the total aboveground plant coverage. As such, the higher number of plants in the dense plot (D) could enhance the F/B ratio through ecological complementarity effects such as a higher supply of resources for microorganisms (Lange et al., 2014). The microbial networks thereupon contribute to the soil-root bonding, transfer of lifted water, and nutrient sharing between plant species, thus enhancing plant growth and soil stability in the study area (Prieto et al., 2016; Montesinos-Navarro et al., 2019).



**Figure 7.** Means total organic carbon of the three experimental plots. Vertical bars indicate the standard deviation, whereas \* and \*\* denote significant differences between plots at  $p \leq 0.05$  and  $p \leq 0.001$ , respectively ( $n = 21$ )



**Figure 8.** Means respiration rate of the three experimental plots. Vertical bars indicate the standard deviation, whereas \* and \*\* denote significant differences between plots at  $p \leq 0.05$  and  $p \leq 0.001$ , respectively ( $n = 21$ )



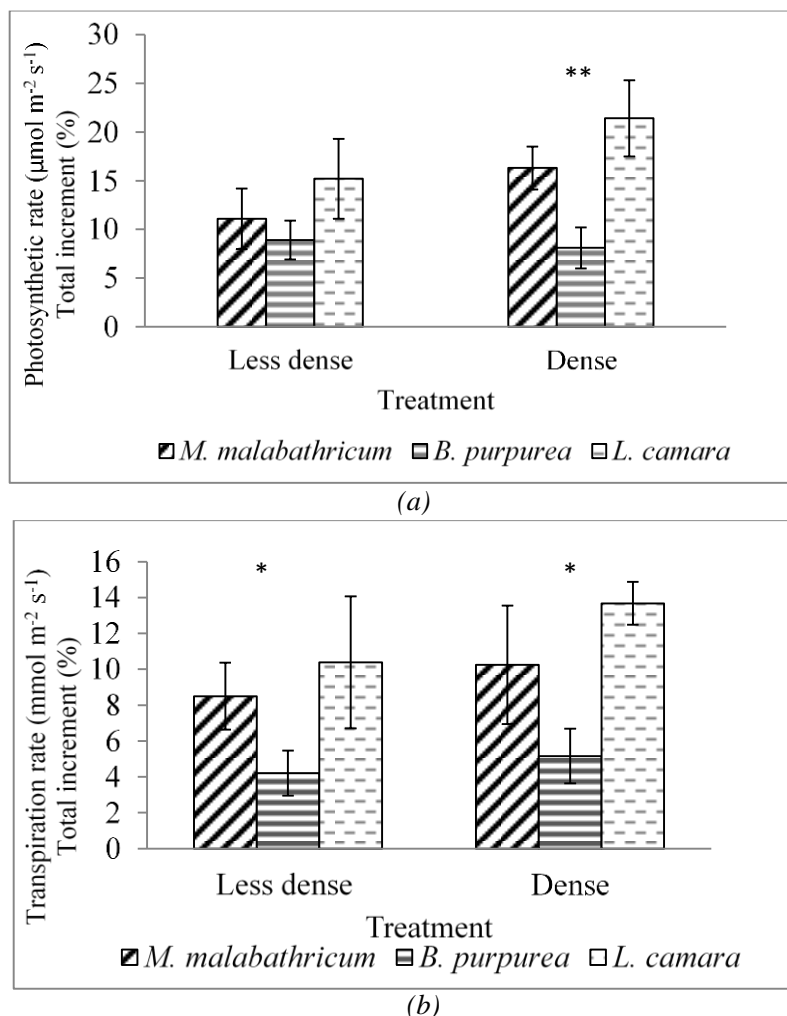
**Figure 9.** (a) Fungal abundance; (b) bacterial abundance; and (c) the fungal:bacterial ratio, F/B of the three experimental plots

### Growth performance of slope pioneers

Vegetation that induced changes in slope soil conditions has further resulted in reciprocal effects that influence the growth performance of the species in this study. For instance, the increase in soil quality and fertility by the dense, mixed-cultured plant community reportedly has a positive influence on the individual plant growth

performance. Further, in terms of photosynthetic rate (A) and transpiration rate (E), it was revealed that *L. camara* exhibited the highest increment in both treatments, followed by *M. malabathricum* and *B. purpurea*. Similarly, to compare between plots, the total photosynthetic increment rate of *L. camara* in the dense plot (D) was also higher with 40.79% than the less dense plot (LD) (Fig. 10).

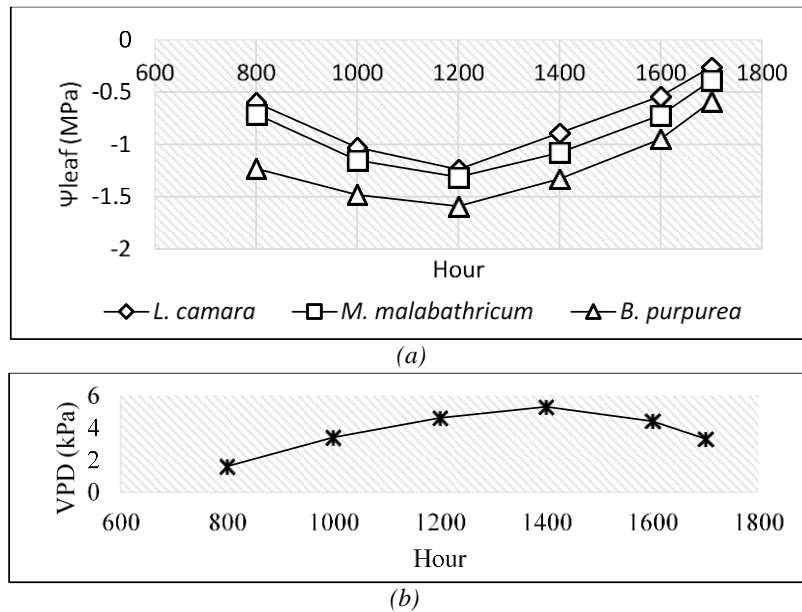
*L. camara*'s sun tolerant feature and its high adaptability to the harsh environment enable this species to have greater growth performance wherein it exhibits the highest value of stomata openings and subsequently induces light utilization efficiency in photosynthesis, transpiration, and biomass production (Sharma et al., 2005; Aoki et al., 2019). Meanwhile, *M. malabathricum* was the second prominent species in this study. This species is highly tolerant and accumulates Al in soil, enabling them to survive and increase their growth performance (Watanabe et al., 2006). Unfortunately, the high soil acidity and Al content reduced the growth performance of *B. purpurea*, hence its decline in dry weight, nutrient uptake, and lower growth performance (Watanabe et al., 2005). In short, although high vegetation coverage is expected to thrive in the highly competitive plant community, the current research findings verify the prominent contribution of the species in this study as outstanding pioneers on the slopes.



**Figure 10.** Total increment of (a) photosynthetic rate and (b) transpiration rate of the species studied at different vegetation coverages. Vertical bars indicate the standard deviation, whereas \* and \*\* denote significant differences between plots at  $p \leq 0.05$  and  $p \leq 0.001$ , respectively ( $n = 27$ )

### Plant water transport

Several studies have revealed that the differences in the growth performance of various plant species affect their plant-soil-water relationship (Buxton et al., 2007). In this study, as vapor pressure deficit (VPD) increases, the diurnal leaf water potential decreases and shows a typical behavior, whereas the increase in transpiration is associated with a decrease in leaf water potential. On average, *L. camara* showed greater diurnal leaf water potential compared to *M. malabathricum* and *B. purpurea* (Fig. 11).



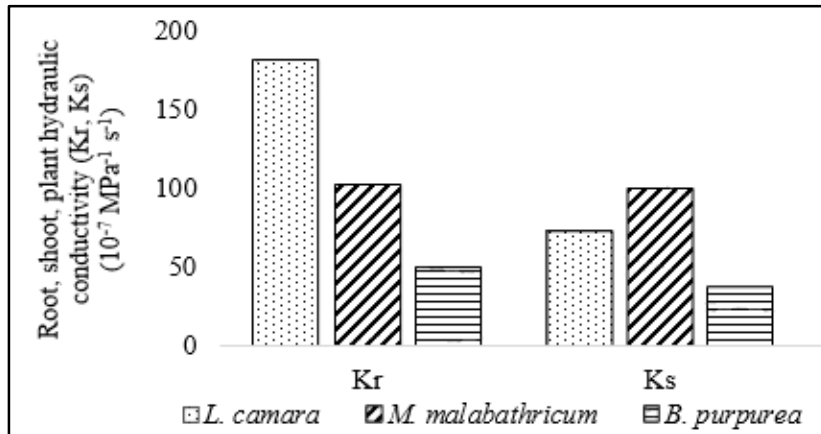
**Figure 11.** Diurnal variation of (a) leaf water potential and (b) vapor pressure deficit of each species

Apart from that, *L. camara* recorded the highest root hydraulic conductance ( $K_r$ ) with 76.7%, which increased threefold compared to *M. malabathricum* and *B. purpurea* (Fig. 12). However, *M. malabathricum* recorded the highest shoot hydraulic conductance ( $K_s$ ) with 36.59% higher compared to *L. camara*. These results show the powerful regulatory mechanisms of each plant to modulate water transport [soil–plant–atmosphere continuum (SPAC)] in response to atmospheric evaporative demand (Martínez-Vilalta et al., 2014). As such, this could be a strategy to reduce air bubble formation in the xylem to avoid cavitation since  $K_s$  is always equivalent to or lower than  $K_r$  for both *M. malabathricum* and *L. camara*. Taking all parameter performance into account, it can be deduced that *L. camara* has an outstanding growth rate performance even in the harsh environment, followed by *M. Malabathricum* and *B. Purpurea* (*L. Camara* > *M. Malabathricum* > *B. Purpurea*).

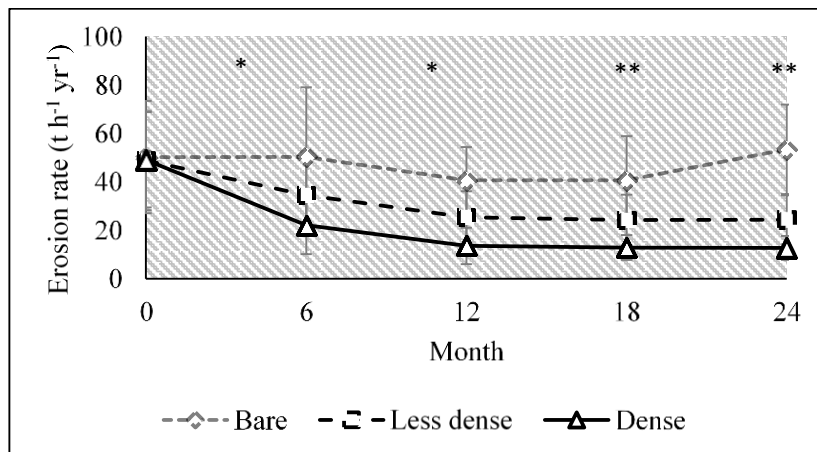
### Soil erosion performance

Given the most enhancement of soil parameters and plant functional traits over time in the revegetated dense (D) and less dense (LD) plots, the erosion rate is also expected to decline with the increase in vegetation coverages. After two years of experiment, the erosion rate shows significant differences between treatments (Fig. 13), with the dense plot (D) yielding significantly lower rates with 47.6% and 76.17% compared to the less

dense (LD) and control (C) plots. Based on these findings, it can be deduced that the species in this study have successfully reflected the performance of plant canopies in interception capacity, thereby delaying the onset to run-off and reducing sediment transport (Zhao et al., 2019). In addition, high root branches of the shrubs and the combination of roots from the neighbouring plants (mixed-culture system) could further promote maximum resistance, and this explains the increased soil penetrability in the revegetated plots in this study (Osman and Barakbah, 2006; Guo et al., 2020) as well as the strengthened effects on the slope stability (Yildiz et al., 2018).



**Figure 12.** Root and shoot hydraulic conductance ( $K_r$  and  $K_s$ ) of each species



**Figure 13.** Means erosion rate of the three experimental plots. Vertical bars indicate the standard deviation, whereas \* and \*\* denote significant differences between plots at  $p \leq 0.05$  and  $p \leq 0.001$ , respectively ( $n = 9$ )

### Which parameters are the most relevant in erosion control?

Overall, the above results imply the influence of revegetation practice on the improvement of slope conditions in two ways, namely through changes in basic soil properties and through SPAC (soil-plant-atmosphere continuum). Thus, it can be inferred that the vegetation-soil processes are complex and clearly not conferred by a single parameter.

Since this study mainly aims to alleviate slope erosion, the study, therefore, found that soil porosity, soil respiration rate, shoot hydraulic conductance, fungal/bacterial (F/B) ratio, and soil organic matter are relevant parameters for assessing the vegetation-soil performance of the areas with similar soil properties as the studied slope in combatting erosion (*Table 2*).

**Table 2.** List of significant relevant parameters of vegetation-soil interaction towards slope erosion performance

Significant variable	P-value (5%)	Confidence interval (97.5%)
Porosity	0.00052	(-1.85544, -0.67769)
Respiration	0.00516	(1.57946, 6.64670)
Shoot hydraulic conductivity	0.00608	(-1.80393, -0.40849)
Fungal/bacteria ratio	0.01607	(1.33659, 8.86063)
Organic matter	0.00034	(21.57223, 56.16040)

The high correlations between these parameters indeed reflected their inextricable associations and simultaneous occurrences in the study area. Hence, the inclusion of these relevant parameters into slope erosion study should be simplified, but they should also be able to practically and fully describe the vegetation-soil performance in alleviating erosion.

## Conclusion

Overall, the results in this study have confirmed that erosion performance in the study area is associated with the dynamic interactions between the plant functional traits, soil parameters, and the microbial properties, which contributions differed simultaneously with vegetation coverages. While the dense and mixed-culture system of the selected slope pioneers exerted promising effects on soil components in the studied slope, the establishment of plants on the compacted and infertile sandy textured soils, on the other hand, has enhanced the soil infiltration via increased porosity, hydraulic conductivity, organic matter accumulation, improved carbon storage, and reduction in soil erosion. Moreover, the success of enhancing plant growth through the modulation of photosynthesis and water transport has clearly verified the potential of *L. camara* and *M. malabathricum* as good slope pioneers. Furthermore, in response to the vegetation of the cut-slope ecosystem, the relevant parameters identified in this study are expected to reflect the changes in soil properties and erosion processes more closely. Finally, the current study has the potential to be improved and expanded for further research; hence, the study recommends that since the identified key parameters in this study are specific to the investigated slope and the outputs might differ due to slope condition variations (e.g. parent material, topography, and microclimatic), the parameters should be expanded to a broader range of slope conditions such as variable slope angles and different plant types should be introduced to capture their involvement throughout the research.

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