PHYSIOLOGICAL RESPONSES OF *MELASTOMA MALABATHRICUM* AT DIFFERENT SLOPE ORIENTATIONS

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ABSTRACT

Raindrops impact and the topographic factor have become part of the major factors affecting soils degradation. In addition, understanding the slope orientation is a critical part of knowing the intensity, amount and directions of sunlight essential for plant growth. Hence, this study is aimed to determine the influence of slope orientations in regard to the sunlight directions, morning sun with evening shade slope where the plant received sun in the morning, and evening sun with morning shade slope where the plant did not receive the morning sun, on the physiological performances of *Melastoma malabathricum* and erosion rate of the slope soils. In six months of observation, the physiological responses of the species studied on morning sun slope were higher in stomatal conductance and photosynthetic rate by 15% and 50.8%, respectively than those on evening sun slope. Whilst the Root Length Density (RLD) of the species studied on morning sun slope recorded the highest value in up to 15cm of soil depth at 77.52 cm m^{-3}. Concomitant to the higher physiological performances, the soil pH and soil carbon content were also higher in the morning sun slope. Interestingly, the erosion rate at morning sun slope was lower by 31% than at the afternoon sun slope, suggesting that the species studied influence the erosion control via increased radiation interception rate. In conclusion, the slope orientation had good effects on the plant growth performance as well as alleviating the soil erosion rate of slope soil.

Keywords: slope orientation, *Melastoma malabathricum*, light intensity, physiological parameters, erosion rate, slope stability.

INTRODUCTION

Malaysia now extensively serves rapid progress for improvement in terms of infrastructure such as slope cutting for highway development as well as the hillside housing project for a better standard of living. Due to poor management system in such areas, the problem of erosion and landslides tend to increase. As a result, government face an increase in economic expenditures from broad damage to property and infrastructure, as well as loss of productive land.

The soil erosion and landslides of the slopes have long been identified as a major abiotic stress and is of great concern as they can cause adverse impact to the environment. In addition, the slope failures mostly occurred in soil cut slopes and then followed by fill slopes (Mohamed & Abdullah 2009). Apart from that, reduction in plant coverage has resulted in increased surface action and the soil loss. Understanding both soil environment and the role of vegetation cover on slope is needed in order to understand the slope limitations and develop systematic and non-destructive methods for mitigation.

Malaysia’s climate is described as typical tropical with warm, high rainfall intensity as well as humid throughout the year. As it experiences high precipitation ranging from 2000 to 2500 mm per annum, the highland areas are prone to erosion and landslides. Generally, the process of erosion includes rainsplash, rilling and gullying, sheetwash, and dry ravel (Menashe 1993) which contribute to soil productivity and water quality degradation. The decrease of the matric suction in unsaturated zone during rainfall infiltration, resulted in reduction of shear strength, thus affecting the factor of safety of the slope and subsequently resulted in erosion and the most adverse impact, the occurrence of landslides (Haihua et al.

2013; Travis et al. 2010). Moreover, soil erosion has been interpreted as an abiotic exploitation agent responsible for the loss of nutrients (Lu et al. 2007). Iin addition, the intrinsic properties of the soil such as aggregate stability, infiltration capacity, soil bulk density and soil texture, organic and chemical content are known as the important determinants towards erosion (Gyssels et al. 2005).

Moreover, it is known that different slope orientation relative to the sun can vary in amount of solar radiation received to the ground. The temporal different in light availability may result in different response to biochemical, physiological and structural changes of the seedlings. Shade also has indirect effects such as reducing leaf and air temperature, vapour pressure deficit and oxidative stress (Holmgren 2000). The impact of solar radiation on plant growth could be attributed to its effect on photosynthetic CO_2 assimilation, a main process for production of biomass (Papadopoulos & Pararajasingham 1997).
An introduction of the conventional engineering approach to slope stabilization and erosion control has been used widely. Installations of new technologies coupled with the progressive engineering designs have led to immediate slope stabilization and erosion abatement. Unfortunately, these applications of structural components become ineffective over time and inadaptable with the changing slope environment. With regard to the need of alternative solution, therefore, the establishment of vegetative elements has become an alternative way for slope stabilizing against erosion as well as minimizing the occurrence of landslides. In addition, the use of vegetation has also been proven to restore the ecosystem accelerating the natural succession process (Normaniza & Barakbah 2011).

Many studies have revealed that in a wide range of environments, the runoff and soil loss decrease with increasing the vegetation cover (Francis & Thornes 1990; Bochet & García-Fayos 2004). Generally, vegetation reduces water-induced soil erosion by intercepting rainfall, increasing water infiltration on associated soil-fertility islands, intercepting runoff at soil surface level, stabilizing the soil by roots (Gyssels et al. 2005), resulting in larger energy needed to detach soil particles (Bochet & García-Fayos 2004) and finally by acting as a roughness element causing flow retardance (Styczen & Morgan 1995). Normaniza and Barakbah (2006) also discovered that the type and vegetation coverage indirectly enhance the water movement from soil to the atmosphere and directly enhance slope shear strength and ultimately influence the stability of the slope. Moreover, Snelder and Bryan (1995) in their research investigated the relationship between plant coverage and soil loss under simulated rainstorms and had found that soil loss was maximum for plant coverage less than 25%, and that a minimum of 55% plant coverage was required to achieve satisfactory soil erosion control.

The vegetation covers offer positive influence towards the erosion control system, hence more information is needed for future improvement in slope stabilization. Thus, this study was undertaken to understand the influence of vegetation on slope stability. Hopefully, it will provide useful information in handling issues of erosion either in smaller scale or in upscale implementation leading to more advance approach towards slope stabilization.

Suitable and favorable erosion control ground cover is essential on slope intended for long term stabilization. In addition, it will contribute for further natural succession processes (Normaniza et al. 2009). There are numerous plant species that grow throughout this country which reflects the site conditions found across the region. A proper species selection is determined by its contribution to the landscape, in this case, the slope areas. The species chosen must be able to grow fast and has an extensive root system (Normaniza et al. 2009). Earlier, it is known that *Melastoma malabathricum* plays an important role as erosion control especially on highly eroded areas (Dafaalla 2004). It is a good choice as it has the tolerance to grow well in harsh environment and has a dense root system that makes it suitable to grow at the sloping area. Finding by Watanabe et al. (2008) has revealed that *M. malabathricum* has the ability to efficiently absorb aluminum (Al) ions from the ground. Furthermore, it was proven by Rohailah (2010) that this species exhibited the highest increment of soil pH and has the ability to rehabilitate the acidic condition of the slope. However, the topography is expected to affect the habitat instability (Mori et al. 2006). Hence, it is crucial to understand the process of the plant development on slope areas. Thus, *M. malabathricum* was chosen as a representative of the potential slope plant in this study to determine the influence of slope orientation with regard to the sunlight directions; morning sun with evening shade slope (the plant receive sun in the morning) and evening sun with morning shade slope (the plant did not receive the morning sun) on its physiological performances as well as in erosion mitigation.

MATERIALS AND METHODS

Plant Material

Seeds of *M. malabathricum* were germinated on the petri dish containing wet cotton at 30^{o}C. Three weeks after germination, seedlings were then transferred to Polyvinylchloride (PVC) pipes (0.1 m in diameter and 0.3 m in height) filled with sandy loam soil and placed in the glasshouse (25 to 32^{o}C, maximum photosynthetically active radiation (PAR) 2100 µmol m^{-2} s^{-1} and relative humidity of 60 to 90%) at the Institute of Biological Sciences, Faculty of Science, University of Malaya. The bottom of the pipes were tied up with plastic netting and perforated to allow drainage. After reaching the average height of 1 m, seedlings of *M. malabathricum* were transferred to the study slopes.

Site Description

Two slopes with the angle percentage of 30% and 100 m^2 in length were selected along the Guthrie Corridor Expressway, Selangor; one received the morning sun with evening shade (the latitude and longitude of N 3^{o} 1' 5.0109" and 101^{o} 5' 2.3556", respectively) and another slope received the evening sun with morning shade (the latitude and longitude of N 3^{o} 1' 5.8769" and 101^{o} 5' 14.8556", respectively). A similar slope angle and berm were taken into consideration for choosing the sites (Table 1). The dominated soil type is slightly acidic, moderately weathered with sandy (70%) and clay (30%).

Table 1. Description of two selected slopes at Guthrie Corridor Expressway, Selangor, Malaysia.

Category	Morning Sun Slope	Evening Sun Slope
Slope angle (%)	30	30
PAR range (µE m^{-2} s^{-1})		
0700-1200 hours	300-2100	150-500
1200-1900 hours	2100-300	1900-200
RH (%)	75-85	50-60

Plot Description

It was clear that the use of small plots were claimed to be an appropriate plot size by the previous studies which used field plots ranging from 1 to 50 m^2 in order to investigate erosion at different soil types, vegetation covers (Bochet et al. 2006) or land use forms (Braud et al. 2001; Descheemaecker et al. 2006; Mathys et al. 2005; Mohammad & Adam 2010). In this study, eight experimental plots with the average area size of 30.25 m^2 (0.5 m buffer zone of each) were set up. Five erosion boxes with the size of 0.25 m^2 were installed in each plot with three replications in Completely Randomized Design (CRD).

Plant Transplanting on Slope

The transplanting of *M. malabathricum* on the slope was done using a Microclimate Plant Propagation Technique with modified soil depth (Normaniza & Barakbah 2011). Each seedling was transplanted into a hole by using a soil coring machine (Model Cobra, Eijelkamp Agrisearch Equipment, Netherlands) at 0.6 m of soil depth. Plant supplements such as NPK fertilizer, sphagnum moss and rock-phosphate (15 g each hole) were applied only in the beginning of treatment in order to initiate the establishment of the roots and other physiological processes. In this technique, the plant roots will establish in a “micro-environment” (hole), which will be more conducive for plant establishment and adaptation. This technique also ensured that the plant species had a higher probability of producing matured plants as compared to conventional seeding (Normaniza & Barakbah 2006).

Physiological performance

Physiological performances such as stomatal conductance, photosynthetic rate, transpiration rate and Root Length Density (RLD) of the species studied were done at monthly interval. Stomatal conductance, photosynthetic rate and transpiration rate were measured using a Portable Photosynthesis System (6400XT, LICOR, USA) in an open system mode during morning and evening, between 9.30 am and 11.30 am with a PAR range between 400 to 2100 µE m^{-2} s^{-1}, and 2.30 pm to 4.30 pm with a PAR range between 2100 to 300 µE m^{-2} s^{-1}, respectively. During the measurements, leaf temperature was set up at similar temperature as ambient value and the ambient CO_2 concentration (C_a) in the cuvette was held at 400 µmol mol^{-1}. At the end of the experiment, the soil samples were sampled in triplicates at 0.45 m of soil depth and 0.1 m around the plant stem using a soil coring machine (Eijelkamp Agrisearch Equipment, Model Cobra, The Netherlands) to determine the RLD. The soils in the cylindrical cores were divided into lengths of 15 cm and soil root length density was calculated as root length per soil volume.

Erosion rate

The eroded soils in the PVC containers placed below the erosion boxes were taken, air dried and weighed weekly for six months. The erosion rate was manually calculated and determined in g m^{-2}. Whilst the predicted measurement of erosion rate was calculated using The Revised Universal Soil Loss Equation (RUSLE) (Renard et al. 1997). The RUSLE relates the rate of erosion per unit area (A) to the erosive power of the rain (R), the soil erodibility (K), the land slope and length (LS), the degree of soil cover (C), and conservation practices (P):

$$A = (R)(K)(LS)(C)(P)$$

Soil Water Profiles and Soil Respiration Rate

Soil water profiles such as soil water content (SWC), soil field capacity (SFC) and soil saturation level (STL) were determined. The soils were sampled using cylindrical soil cores (11 cm in diameter, 100 cm depth). The measurements of SWC and SFC were taken at the beginning and the end of the experiment, diagonally across the plot with three replications, as follows:

(a) Soil water content (SWC)

The soil samples from slope area were oven dried at 85^0C to a constant weight. SWC was calculated as follows:

$$[(\text{Fresh weight} - \text{dry weight})/ \text{Fresh weight}] \times 100\%$$

(b) Soil field capacity (SFC)

SFC was determined by pouring excess water into a container filled with soil so that the soil becomes supersaturated. The excess water was drained out through small holes at the bottom of the container. Once the water stopped dripping, the saturated soil was weighed (SW) and then dried in the oven at 85^0c to obtain a constant weight (DW). SFC was calculated as follows:

$$[(SW - DW)/SW] \times 100\%$$

(c) Soil saturation level (STL)

The soil saturation level was determined using the formula as follows:-

$$[SWC / SFC] \times 100\%$$

At the end of the experiment, the soil samples were sampled in triplicates at 0.45 m of soil depth and 0.1 m around the plant stem using an undisturbed soil coring machine (Model Cobra, Eijelkamp Agrisearch Equipment, Netherlands) to determine the soil CO_2 value. The soils in the cylindrical cores were divided into lengths of 15 cm and CO_2 was measured using the closed system respiration chamber (EGM-4 CO_2, PP Systems, USA).

Statistical Analysis

Statistical analysis was calculated using SPSS version 20. The one-way ANOVA was applied to evaluate the significant difference of the parameters studied at different slope orientation treatments. LSD (p=0.05) was calculated using the error mean squares of the analysis of variance.

RESULTS AND DISCUSSION

Physiological Performance

Stomatal Conductance and Photosynthetic Rate

In general, the stomatal conductance of the plant species studied on the morning sun slope was significantly higher as compared to the same species grown on evening sun slope (Figure 1). The results implied that the stomata opening was influenced by the light intensity of the slopes chosen (Table 1). Moreover, in response to a higher RH and the optimum PAR received from early morning to afternoon on morning sun slope, the stomatal conductance increased, hence, affecting the CO_2 uptake of the species studied. This was in accordance with the finding by Yang et al. (2008) that the plant photosynthesis was easily affected by the environmental factors including light, temperature and CO_2 concentration. On the evening sun slope, the light intensity was higher in the afternoon to evening that caused an increase in temperature. Thus, stomata tend to close in order to minimize the water loss. Ultimately, the reduced diffusion of CO_2 through the closed stomata would limit the CO_2 fixation in chloroplast, decreasing the photosynthesis (Prasad e al. 2008).

Moreover, the plant species studied on morning sun slope recorded a significantly higher photosynthetic rate. The results showed that the photosynthetic rate of seedlings grown on morning sun slope was higher by 50.8% than those grown on evening sun slope (Figure 2). As plant growth increased with time, with higher plant canopy size, implying that optimal leaf area maximized the canopy photosynthesis via an increased amount of intercepted photosynthetically active radiation (IPAR) (Margolis et al. 1995). This helps in enhancing the exchange of carbon dioxide and water vapor that are essential for plant growth and also increasing the plant productivity (Hirose et al. 1997). Furthermore, the poor physiological performance of plant on evening sun slope can be explained by the adaptation of stomata of which they tend to close in the evening due to low light intensity resulting in lower CO_2 intake and ultimately affecting photosynthesis (Lawlor & Tezara 2009; Chaves et al. 2009). Moreover, decline in stomatal aperture is accompanied by the adjustment of leaf area and led to decrease of transpirational area as well as lowering the intercepted light, thus decreasing biomass production (Pereira & Chaves 1993).

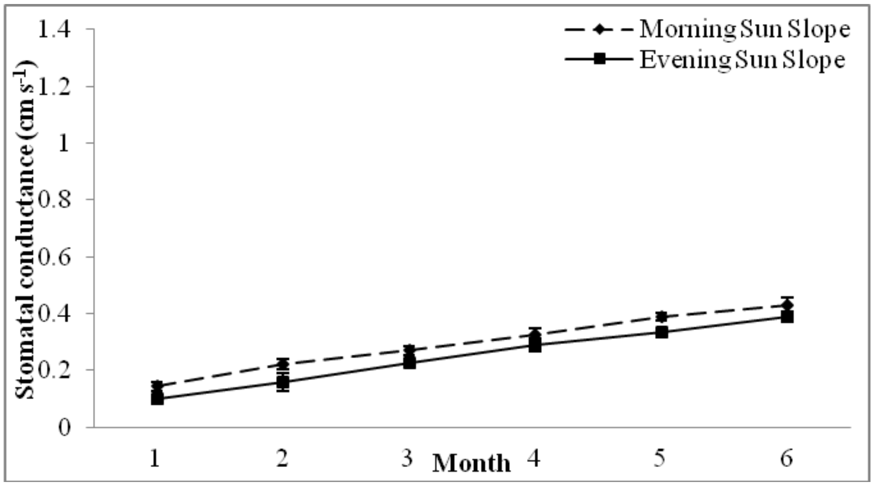


Figure 1. Stomatal conductance of the plants studied on different slope orientations

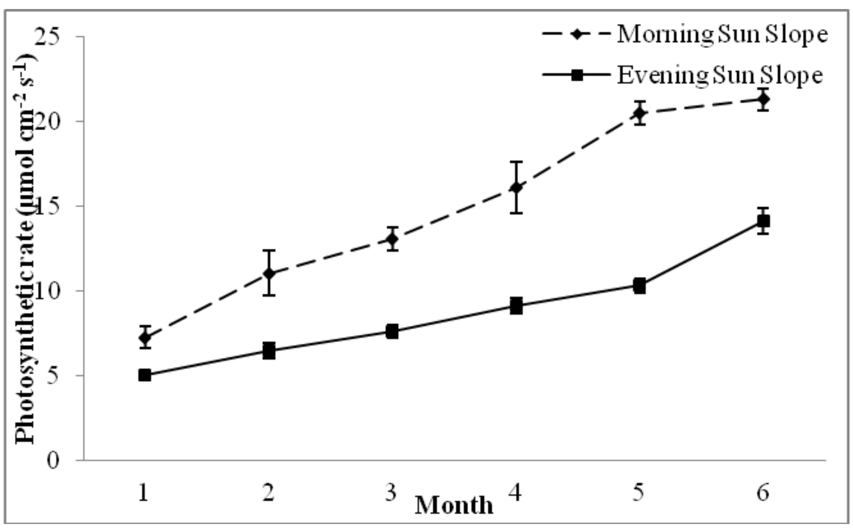


Figure 2. Photosynthetic rate of the plants studied on different slope orientations

Root Length Density

After six months of observation, a higher root length density (RLD) was recorded up to15 cm of soil depth on morning sun slope which was 77.52 cm m^{-3} (Figure 3). This result implied that the higher root length would maximize the soil-root interaction (Normaniza & Barakbah 2006) and it would reduce the soil erosion (Figure 3). Moreover, finding by Kumar et al. (2010) had revealed that higher root volume will provide a promising characteristic to enhance the physiological performance of the plant. While lower light intensity during afternoon onwards at evening sun slope affected the physiological performance of the species studied (Figure 1 and 2), thus lowering the value of RLD. Moreover, higher plant density causes increase in organic matter at the top layer of soil, hence enhancing the root formation. Roots and organic matter physically bind the soil particles and produced an increased soil aggregation, thus able to reduce the soil erosion. This was in line with Reubens et al. (2007) that proposed the combination of shallow but dense root networks of fine roots might be most beneficial to control soil erosion processes. Furthermore, the below-ground root systems are essential in shallow slope stabilization by controlling both hydrological and mechanical properties of the slope soil (Gyssels et al. 2005; Reubens et al. 2007).

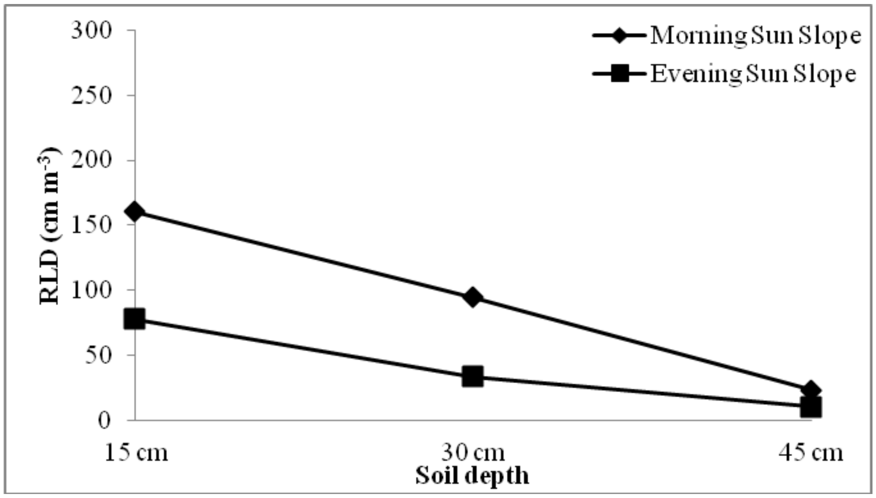


Figure 3. Root length density (RLD) with soil depth with the plants studied on different slope orientations

Erosion rate

After six months of observation, the plot grown with the plant species studied on morning sun slope recorded a significantly lower value of the erosion rate (Figure 4), indicating that the optimum light intensity received by morning sun slope contributed the most to the higher growth rate of the species. In addition, as the light radiation levels increased from morning to afternoon on morning sun slope (Table 1), the plants tend to open their stomata in order to increase the CO_2 uptake, enhancing their physiological performance (Lunagaria & Shekh 2006) and growth rate. Furthermore, it is known that the light intensity and CO_2 are the main limiting sources of plant photosynthesis when water and nutrient are not limiting. The varying light intensity (Table 1), air temperature and soil moisture on morning and evening sun slopes led to variations in photosynthetic rates and other physiological parameters. The lower light intensity received by the species studied on the evening sun slope made the vegetation difficult to establish which consequently reduced the physiological performance of the plant, lowering its growth rate hence resulted in a higher soil erosion. Moreover, the trend of the measured erosion rate was consistently reduced at both slopes, suggesting that the presence of the species studied had reduced the water-induced soil erosion by intercepting rainfall at soil surface level and stabilize the soil by the roots (Gyssels et al. 2005) resulting in a larger energy needed to detach soil particles (Bochet & Garcia-Fayos 2004).

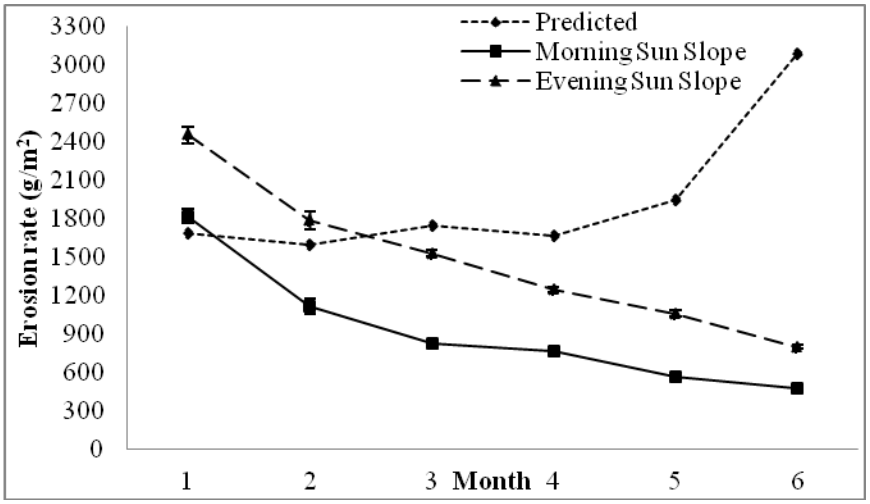


Figure 4. The erosion rate on different slope orientations grown with *M. malabathricum*

Soil Water Profiles

The species studied grown on morning sun slope showed a lower percentage of Soil Saturation Level (STL) than those on the evening sun slope (Figure 5). The results indicated that the spread of root in the soil (Figure 3) helped the species to obtain a larger spatial distribution in water uptake (Zhou et al. 2013). The positive interaction between plant growth and water absorption capacity (WAC) by root exhibited a positive effect towards soil water profiles by ameliorating the harsh physical conditions (Callaway et al. 2002). Moreover, at higher WAC, the plant will reduce the soil water content and alleviate the soil detachment (Normaniza & Barakbah 2006). Furthermore, the species studied on morning sun slope experienced the optimum light intensity than those on evening sun slope, thus resulting in a higher growth rate and subsequently, lowering the soil saturation level of the slope soil. Thus, it can be assumed that the role of the plant species studied had a hydrological characteristic via increasing the water absorption capability as well as lowering the potential of slope failure (Normaniza & Barakbah 2006).

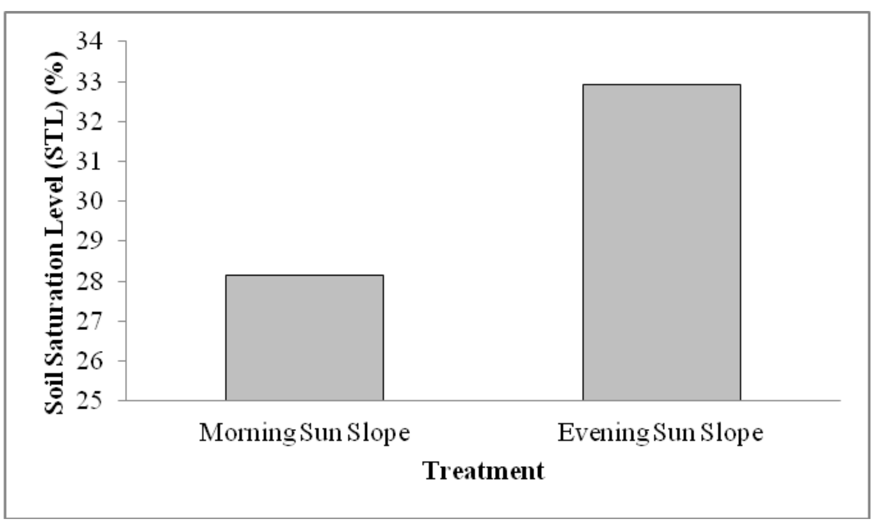


Figure 5. Soil saturation level (STL) of both slopes grown with *M. malabathricum*

Soil Respiration Rate

At the end of the experiment, the soil respiration decreased with increasing soil depth. The species studied grown on morning sun slope exhibited the higher CO_2 by 33.4% at 0 to 15 cm of soil depth than that on evening sun slope (Figure 6). This result indicated that the species studied influenced in carbon cycle via storing the large amount of carbon in soil through photosynthesis and respiration (Mahdavi et al. 2012). Concerning the decrease respiration rate with increasing soil depth, it can be explained by the large amount of litter fall on the soil surface, thus enhancing the decomposition process which in turns, increased the organic matter and mineral content at the top layer of the soil. The morning sun slope having the optimum light intensity for the plant growth, subsequently, enhanced the physiological performance of the species studied, thus leading to a greater amount of soil respiration process.

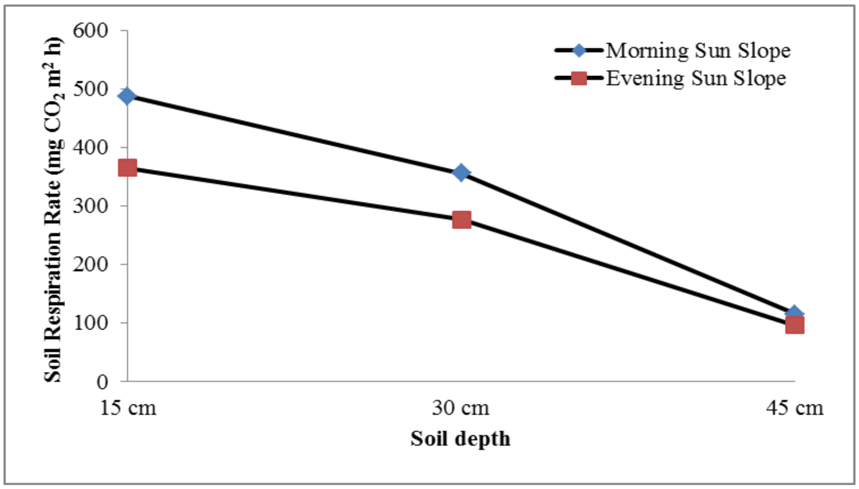
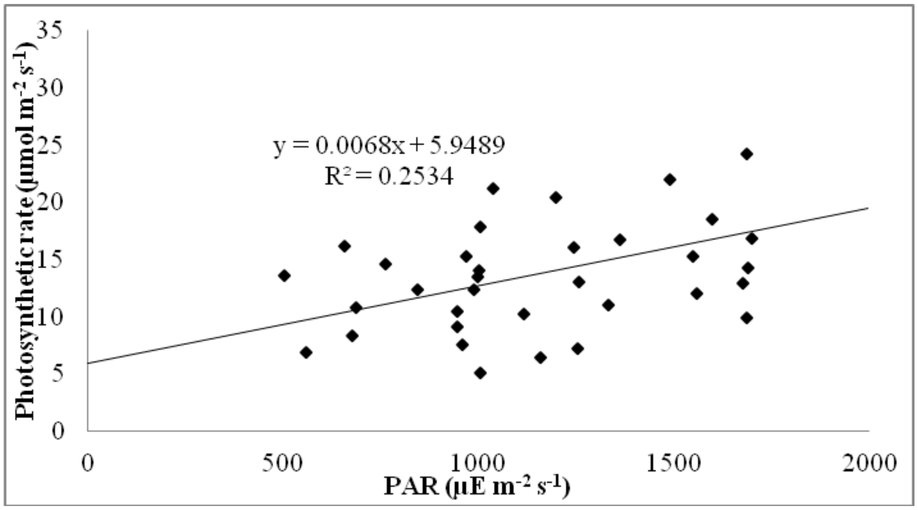


Figure 6. Soil respiration rate with soil depth on different slope orientations

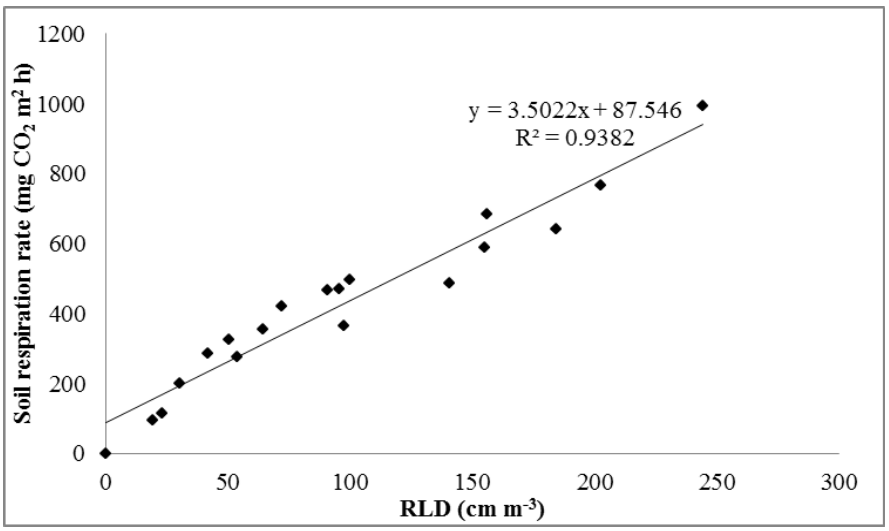
Correlations amongst Parameters Studied

All treatments exhibited a positive relationship between light intensity and photosynthetic rate (Figure 7a). The increased light intensity exhibited a higher photosynthetic rate. It is known that plant growth is a function of metabolic processes which is influenced by environmental and genetic factors (Özalkan 2010). In this study, as the light intensity increased during morning until afternoon on morning sun slope, it led to increased stomata opening, thus higher photosynthetic rate of the species studied (Figure 2).

Furthermore, there is a strong correlation between soil respiration rate and root length density (Figure 7b). A higher soil carbon was observed at the area with the greater root biomass. The root systems supply the soil with decomposable organic matter and support a large microbial community in the rhizosphere (Gyssels et al. 2005), thus help in distribution of soil carbon. Moreover, as the soil surface on evening sun slope had higher soil temperature, it led to the distribution of soil carbon deeper in soil (Jobbágy & Jackson 2000) as an adaptation to the harsh environment.



(a) Light intensity (PAR) and photosynthetic rate



(b) Soil respiration rate and Root Length Density (RLD)

Figure 7. Relationships among parameters studied on different slope orientation grown with *M. malabathricum*

CONCLUSION

M. malabathricum had shown an outstanding performance on improving the slope environment and alleviating the erosion problem. The morning sun slope had optimum light intensities that enhanced the physiological performance of the species and had a positive influence on the erosion rate of the slope soils. This study has proven that *M. malabathricum* had reduced the soil erosion rate on the slope and could become a key factor in bioengineering development towards slope stabilization.

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