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The Effects of Pre-Aluminum Treatment on Morphology and Physiology of Potential Acidic Slope Plants

Normaniza Osman, Mohammed Saifuddin *, Aimee Halim and Rohailah Mohamad Idris

Institute of Biological Sciences, Faculty of Science, University of Malaya, 50603
Kuala Lumpur, Malaysia. Tel: +60172017345; Fax: +603-7967-4178
* saifuddin@siswa.um.edu.my

Abstract: In Malaysia, most of the slope soils become acidic due to high temperature and rainfall. In the case of acidic slope, these conditions result in a low plant coverage, high eroding potential and instability of slopes. Thus, this study is aimed to investigate the effect of pre-Aluminum treatment on the growth and development of selected plants on acidic slope conditions. The acidic-tolerant characteristics of *Acacia mangium*, *Leucaena leucocephala* and *Melastoma malabathricum* were determined by subjecting them into pre-aluminum treatment at germination phase. The results showed that *M. malabathricum* was higher in morphological parameters; root length and dry weight partitioning and physiological performance including photosynthetic rate, stomatal conductance, transpiration rate, Leaf Area Index (LAI), and leaf aluminum analyses. Within ten weeks of observation, the Al-pretreated *M. malabathricum* showed the highest photosynthetic and transpiration rate as compared to *L. leucocephala* and *A. mangium*. In concomitant to this result, stomatal conductance also appeared to be the highest in *M. malabathricum*. Moreover, within ten weeks, soil pH planted with *M. malabathricum* on slope increased by 23.8% and was found to be the highest among the species studied, implying the rehabilitation capacity of this species. The Al-pretreated *M. malabathricum* also displayed the longest root length in acidic soil, exhibiting a tolerance mechanism towards acidity. Amongst the species studied, *M. malabathricum*, either treated or non-treated, showed the best morphological and physiological performance on acidic condition.

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Keywords: Acidic slopes, Acidic-tolerant plants, Soil rehabilitation, Slope stability, Aluminium treatment

1. Introduction

The intensive development of infrastructures on hill slopes such as housing, agriculture, and highways has become a big concern due to the exposure to landslide hazards and erosion problems (Mafian *et al.,* 2009; Huat and Kazemian, 2010). As a result of massive human miscalculation and mismanagement to nature especially on slopes, the creation of bare and steep surfaces will increase the need of vegetation to provide stabilization (Komoo et al., 2011; Mugagga *et al.,* 2012; Song *et al.,* 2012). Although the establishment of vegetation is important, the criterion to fix the need is limited due to adverse conditions of the slope, mainly climate and soil properties (Bochet and García-Fayos, 2004; Normaniza and Barakbah, 2006).

In Malaysia, the annual average rainfall of nearly 2,500 mm can generate great potentials of accelerated erosion, often leading to landslide (Shafie, 2009). Besides, Pradhan et al. (2012) discovered that deforestation in Malaysia has adverse effects on the hydrological cycle, particularly relating to increase in runoff and erosion. In exposed conditions, almost the entire volume of rain hits the surface and flows as runoff in a short time, leads to structural weaknesses in the soil as well as destroying the topsoil (Mafian *et al.,* 2009; Huat and Kazemian, 2010). In addition, lack of vegetation coverage also may result in surface runoff that consequently increases the landslide risk. Apart from that, most of the soil in the tropical region becomes arid and barren due to lack of buffer capacity and low clay activities which resulted in soil acidity (Koutika *et al*., 2002). The rain water percolation which leaches away basic elements such as calcium, magnesium, potassium, and sodium from the soil profile is also another factor on development of soil acidity. The main trait of soil acidity is low pH value which mainly attributed by high concentration of aluminum (Al), as well as other acid-caused elements like manganese (Mn), hydrogen (H) and iron (Fe) (Kochian *et al.,* 2004). Zsoldos *et. al*., (2003) reported that aluminum toxicity is the primary stress factor limiting the growth of plants in acid soils.

Soil acidity has a negative impact on fertility, biological activities and plant productivity. Acidic land is known as infertile, barren and not suitable for the purpose of agriculture due to the occurrence of toxic elements like aluminum and manganese. These elements become a problem in soils because they are more soluble at low pH (Copeland *et al.,* 2012; Wang *et al.,* 2006). Moreover, at soil pH values at or below 5, dissolution of Al-bearing minerals results in toxic aluminium (Al) forms, inhibiting root growth and function, and thus reducing crop yields (Kochian *et al.* 2005). In other words, more of the solid form of these elements will dissolve in water when the pH is acidic. There is always a lot of aluminum present in soils because it is a part of most clay particles. In addition, soil acidity also affects the effectiveness of soil microorganism activities (Fuentes *et al.,* 2006). As soil pH levels decline so does the activity of the organisms which decompose the organic matter. It affects the level of releasing nutrients by soil for plant growth. Although these organisms function best at soil pH levels of 8.0, their effectiveness does not drop rapidly until pH levels drop below 6.0. Decomposition of organic matter also contributes to aggregation of soil particles which provides good aeration and drainage (Kidd and Proctor, 2001). In order to enhance the slope stability, the acidity is one of the major factors that should be reduced by eliminating the acidic element which in most cases caused by Al.

Liming is one of the conventional methods that widely used to correct acidity. However, this method is claimed to be not cost effective and caused soil pollution. Therefore, the needs to identify the potential acidic slope plants are essential. The potential acidic slope plant must be an aluminum accumulator as this plant will accumulate high concentration of aluminum from the soil into its parts, for example root and shoot (Misawa *et al*., 2005). As a result, the aluminum concentration of the acidic slope could be reduced. There are a numbers of studies that have been conducted to assess the success of the common species for slope stabilization rely on its deep rooting system (Normaniza, 2004; Rohaila, 2011). Soil acidity inhibits the elongation and interconnected of root system, which reduced the nutrient and water uptake, consequently resulting in the poor plant growth and slope coverage. Vegetation contributes to slope mass stability by increasing soil shear strength *via* root reinforcement (Normaniza and Barakbah, 2011). The stunted root profile in acidic slope causes difficulty for the root to bind soil and prevent soil losses especially due to the rainfall (Harter, 2002). Thus, this hydrological factor together with morphological influence by poor root profile may become one of the major causes of previous erosion and landslide disasters (Cruden and Varnes, 1996; Normaniza *et al.,* 2008).

As most of the plant could not survive on acidic slope, all three species studied namely *Acacia mangium*, *Leucaena leucocephala* and *Melastoma malabathricum* were exposed to the high Al concentration (pre-acidic treatment) before transferring them into the real acidic condition of the slope. It is anticipated that the Al pre-existence in the Al-pretreated plant would be more adapted to acidic condition of the slope. Hence, the aim of this study are to assess the morphology and physiology of the species studied, either control or Al-treated. The morphological and physiological adaptation and the rehabilitation of soil in terms of soil pH was also monitored.

2. Material and Methods

Plant materials- laboratory and glasshouse experiments: The seeds of all species studied were germinated on moistened cotton in petri dish at the temperature of 25°C for 7 days in the laboratory. The seedlings labeled as Al-pretreated were pre-cultured for 2 weeks on the treatment solutions as follows: 200 µM K_2SO_4, 200 µM $CaCl_2$, 100 µM $MgSO_4$, 200 µM $Ca(NO_3)_3$, 300 µM NH_4NO_3, 5 µM NaH_2PO_4, 10 µM Fe-EDTA, 5 µM $MnSO_4$, 0.38 µM $ZnSO_4$, 0.16 µM $CuSO_4$, 8 µM H_3BO_3, 0.06 µM $(NH_4)_6Mo_7O_{24}$, 50 µM Al (Tolrá *et al.*, 2005). The same treatment solutions were applied for the control species without the element of aluminum.

This solution was renewed twice per week to prevent the fungal activities. The seeds were grown in a growth chamber under the light condition of 330 µE m^{-2} s^{-1}, photoperiod of 16 h light/8 h darkness, day/night relative humidity of 50%/80%, day/night temperature of 24 °C/18 °C (Tolrá *et al.*, 2005). After 2 weeks, the seedlings with uniform height of 10 cm were transferred into polythene bag in the glasshouse (temperature 25-32°C, maximum PAR 2000 µE m^{-2} s^{-1} and relative humidity of 60-90%) located at Rimba Ilmu, University of Malaya.

Experimental Design: Six plots (each plot of 6 m x 2 m = 12 m^2) in a Completely Randomized Design (CRD) have been set up on the experimental slope in a total area of 102 m^2, including 6 m^2 of buffer zone between the plots, and 60° of slope angle. The plots had the same soil type, acidic soil (Table 1; Saifuddin *et al.,* 2013) with pH ranged from 4.70 to 4.90 (Al concentration = 2757 ppm, relative humidity of 70-90%, temperature 32-38°C, maximum PAR 2025 µE m^{-2} s^{-1}), at Section 16 (longitude E 101° 39' 0", latitude N 03° 07' 45"), University of Malaya (Saifuddin and Normaniza, 2012). After 5th week observation, the Al-pretreated and controlled plants in the glasshouse which reached 50 cm of height were transferred to the slope. The transplanting of both Al-pretreated and control species was conducted using a modified Microclimate Plant Propagation Technique (Normaniza and Barakbah, 2011). Each seedling was transplanted into a hole at 0.6 m of soil depth on the slope (Fig. 1) with additions of plant supplements such as NPK fertilizer, sphagnum moss (15 g/hole) and rock-phosphate which were only applied with soil in the beginning of planting in order to allow the establishment of the roots and other physiological processes of the plants. The information of the plots was described in Figure 2. In slope condition, the species studied were grown for another 10 weeks.

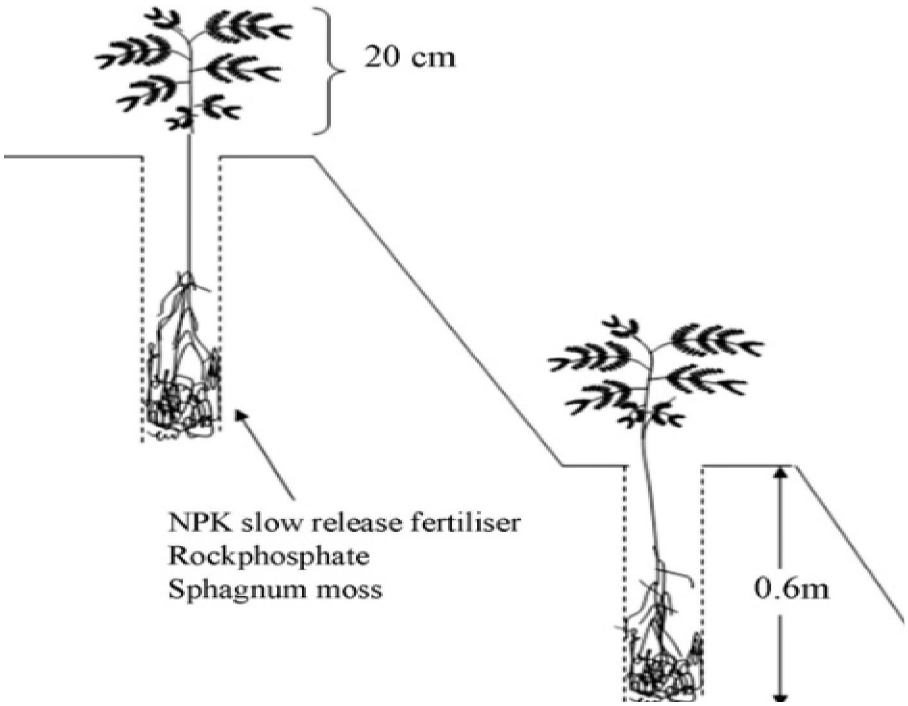

Fig. 1: Plant propagation technique on slope.

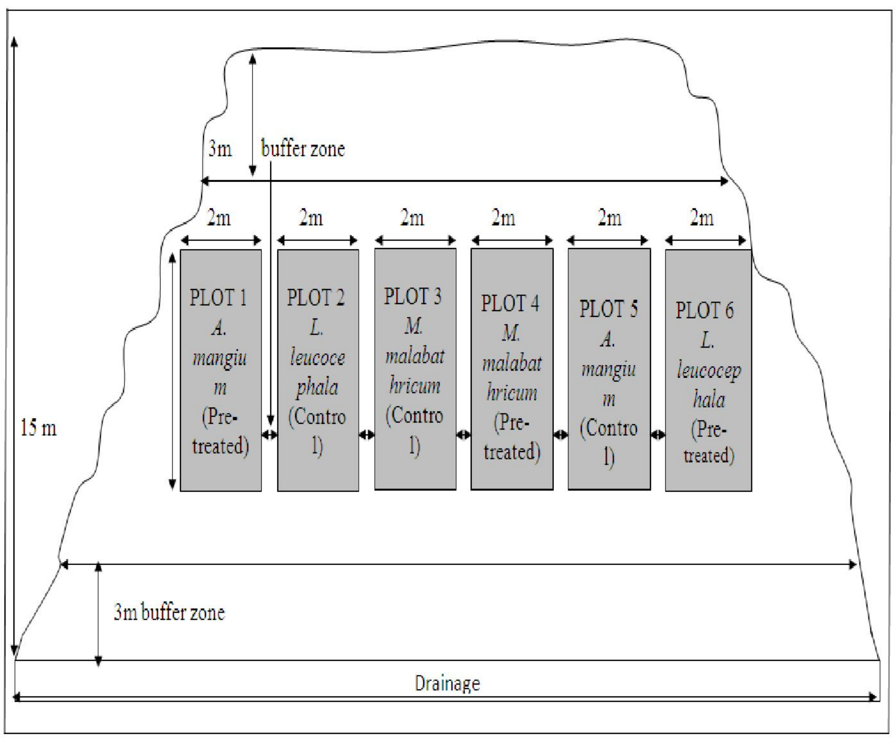

Fig. 2: Experimental design on slope

Table 1: Physical properties of the soil used in this experiment.

Soil properties	Slope soil
Specific gravity	2.62
Liquid limit	26.9%
Plastic limit	14.5%
Dry unit weight (kN/m^3)	13.1
Soil Field Capacity	20.3 %
pH	4.7-4.9
Color	6/8/Hue 10 [Bright yellowish brown]
Type	Size distribution
500 to1.0 mm	12.165 %
250 to 500 mic	29.45 %
100 to 250 mic	38.58 %
50 to100 mic	13.14 %
<2 to 50 mic	6.64 %

Morphological Parameters: Root Length and Dry Weight Partitioning**:** Root length and dry weight partitioning of stem, leaf and root were obtained at the end of each treatment on week tenth. All parts were oven-dried (80°C) until they reached the constant weight.

Photosynthetic, Transpiration Rates, and Stomatal Conductance: Both photosynthesis and transpiration rates were measured using portable photosynthesis system (LICOR, Li-6400XT, USA) and portable porometer (SC-1, Decagon, USA) was used to measure stomatal conductance. Five young expanded leaves of each species were measured randomly. The measurements were taken between 12 p.m. – 2 p.m. with a range of PAR 1800-2100 $\mu E\ m^{-2}\ s^{-1}$ (normal PAR of 1500 $\mu E\ m^{-2}\ s^{-1}$).

Leaf Area Index (LAI) and Leaf Aluminum Concentration: At 7-day interval, Leaf Area Index of the species was measured using leaf area instrument (AccuPAR-LP80, UK). At the end of experiment, the plants were harvested and oven-dried at 80°C to a constant dry weight. The leaves in triplicates of the species studied were thoroughly washed and rinsed with distilled water. The samples were dried in oven at 40°C and ground into fine powder and stored in fresh plastic polythene bags. The powdered samples of the leaves were digested by wet digestion method and the Al concentration of leaf was determined by using atomic absorption spectrophotometer (Dhiman *et. al.,* 2011).

Soil Analysis- Soil pH: In order to determine the rehabilitation process of the acidic slope, soil was analyzed. Both parameters were measured diagonally across the plot with three replications. The measurement was taken at 7 days interval for ten weeks using a pH meter (pH meter BASIC 20, CRISON, Barcelona) at 0.5 m of soil depth and 0.5 m around the plant root.

Statistical Analysis: Statistical analysis was performed using SIGMAPLOT 2000. The one way ANOVA was applied to evaluate the significant difference of the parameters studied in two different treatments (one factor). LSD ($p=0.05$) was calculated using the error mean squares of the analysis of variance.

3. Results

Morphological Parameters- Root Length: The root length of both Al-pretreated *M. malabathricum* and *L. leucocephala* reached more than one meter of soil depth after ten weeks of experiment (Fig. 3). In fact, the root length of Al-pretreated *M. malabathricum* and *L. leucocephala* was almost four and three fold of the root length of Al-pretreated *A. mangium*, respectively. However, the root length of Al-pretreated *A. mangium* was significantly lower than the control treatment.

Dry Weight Partitioning: All species studies showed higher leaf dry weight in its Al-pretreated plants than in control plants (Fig. 4), *M. malabathricum* exhibited the highest among the test species. In contrast, the shoot dry weight for all Al-pretreated species was significantly lower than the control. The similar result was observed for root dry weight of Al-pretreated *A. mangium* but not in the other two species. Interestingly, in all Al-pretreated species, *M. malabathricum* exhibited the highest total biomass, followed by *L. leucocephala* and *A. mangium*, respectively. The same trend was found in all control species. Overall, total biomass for every species is higher in Al-pretreated plants than in control plants except for *A. mangium.*

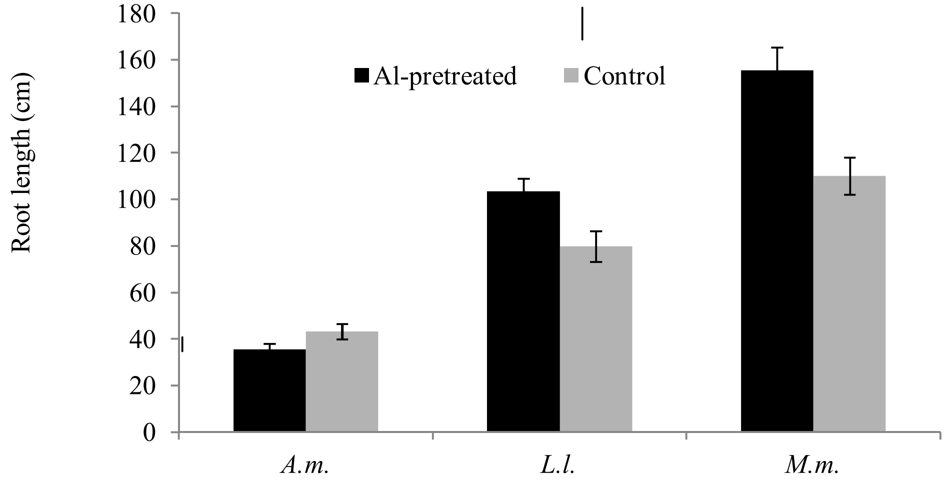

Fig. 3: Root length of the species studied after ten weeks of treatment. Vertical bars represent standard deviation.

Physiological Parameters- Photosynthetic Rate, Stomatal Conductance and Transpiration Rate: The entire Al-pretreated species showed significantly higher photosynthetic rate compared to the control. Photosynthetic rate of Al-pretreated *L. leucocephala* was almost twice than that of control (Fig. 5). Likewise the transpiration rates of all Al-pretreated species studied (except *A. mangium*) were significantly higher than the control. The highest transpiration rate was shown by *M. malabathricum*, followed by *L. leucocephala* and *A. mangium* in both treatments. In the case of *L. leucocephala*, there was no positive effect of pre-aluminum treatment on stomatal conductance. The stomatal conductance for Al-pretreated *M. malabathricum* and *A. mangium* were significantly higher than the control.

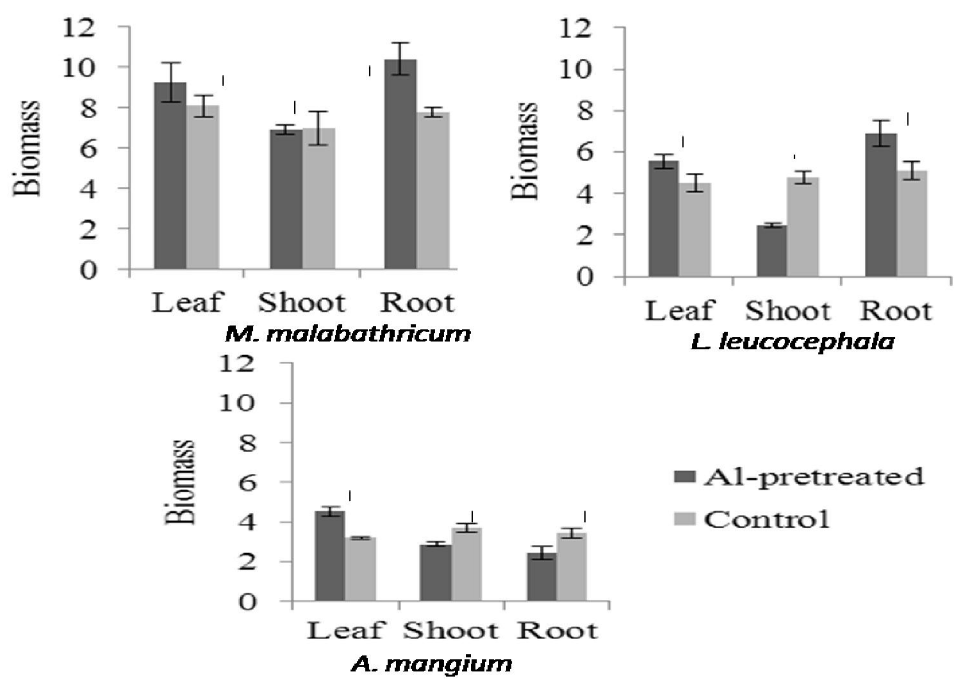

Fig. 4: Comparison of dry weight partitioning of the species studied. Vertical bars represent standard deviation and vertical lines represents $LSD_{p<0.05.}$

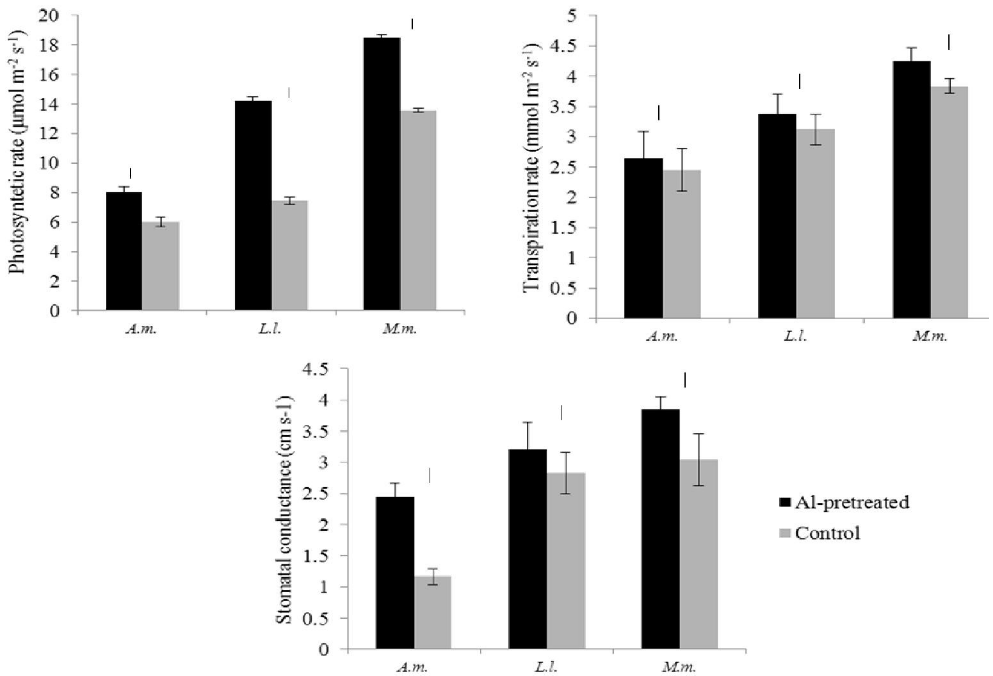

Fig. 5**:** Comparison of physiological performance of the species studied. Vertical bars represent standard deviation and vertical lines represents $LSD_{p<0.05}$.

Leaf Area Index (LAI) and Leaf Aluminum Analyses: Leaf Area Index (LAI) of Al-pretreated *A. mangium* was significantly lower compared to the control (Fig. 6). Unlike *A. mangium*, the LAI of *L. leucocephala* and *M. malabathricum* were significantly higher in Al-pretreated compared to control. However, the Al-pretreated *M. malabathricum* performs well in the parameter studied, almost doubled than the Al-pretreated *L. leucocephala*. The results showed that the Al concentration in the leaves of all Al-pretreated species was two to four folds higher than the control at the beginning of the experiment (Fig. 7).

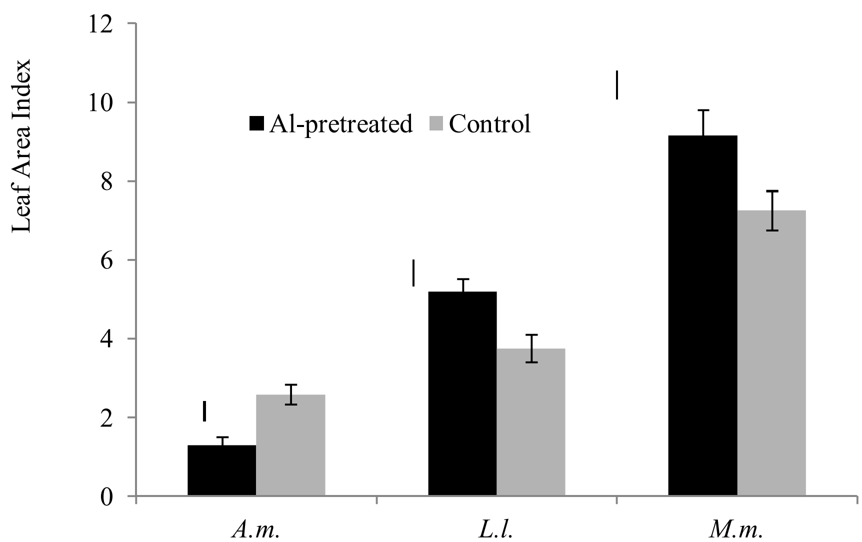

Fig. 6: Leaf Area Index (LAI) for Al-pretreated and control plants on experimental slope. Vertical bars represent standard deviation and vertical lines represents $LSD_{p<0.05}$.

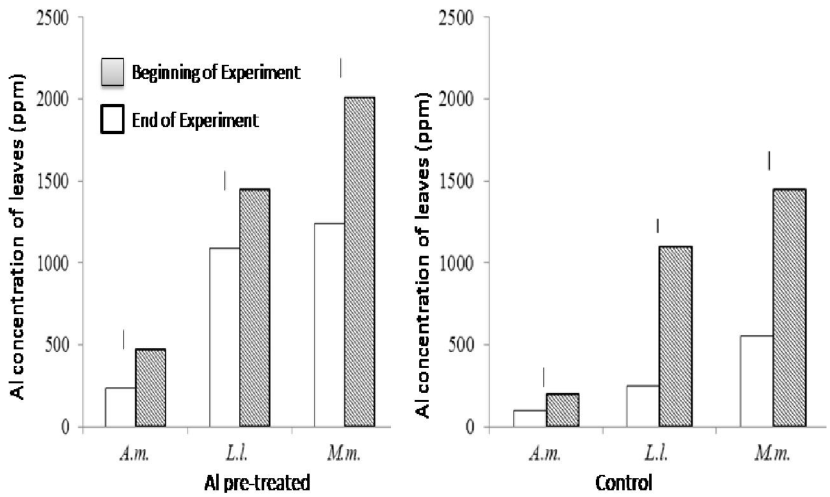

Fig. 7: Al concentration of leaves of three species studied in the beginning of experiment and at the end of experiment. Vertical lines represents $LSD_{p<0.05}$.

Soil pH: Soil pH of the slope was measured for ten weeks of experiment for plot grown by Al-pretreated and control species (Fig. 8). In the beginning of experiment, soil pH at the slope was ranging from 4.70 to 4.90 for every plot before those species were transferred to the slope. After transplanting, there was a significant increment in the soil pH. At the end of experiment, plot grown with Al-pretreated *M. malabathricum* (Plot 6) exhibited the highest increment in soil pH with 23.8%, followed by *L. leucocephala* (16.0%, Plot 5) and *A. mangium* (7.5%, Plot 1). The same trend was found in the plot grown by control species though the results for control plots were more consistent than those of Al-pretreated species. This was due to the soil pH that had dropped rapidly at week three and four respectively, before increasing the pH value in the following week. Nonetheless, at the end of the current experiment, the soil pH for the plot grown by Al-pretreated *M. malabathricum* was 5.99, *L. leucocephala* (5.59) and *A. mangium* (5.32). Meanwhile for control, the value of soil pH grown with *M. malabathricum* was 5.60, *L. leucocephala* (5.42) and *A. mangium* (5.12).

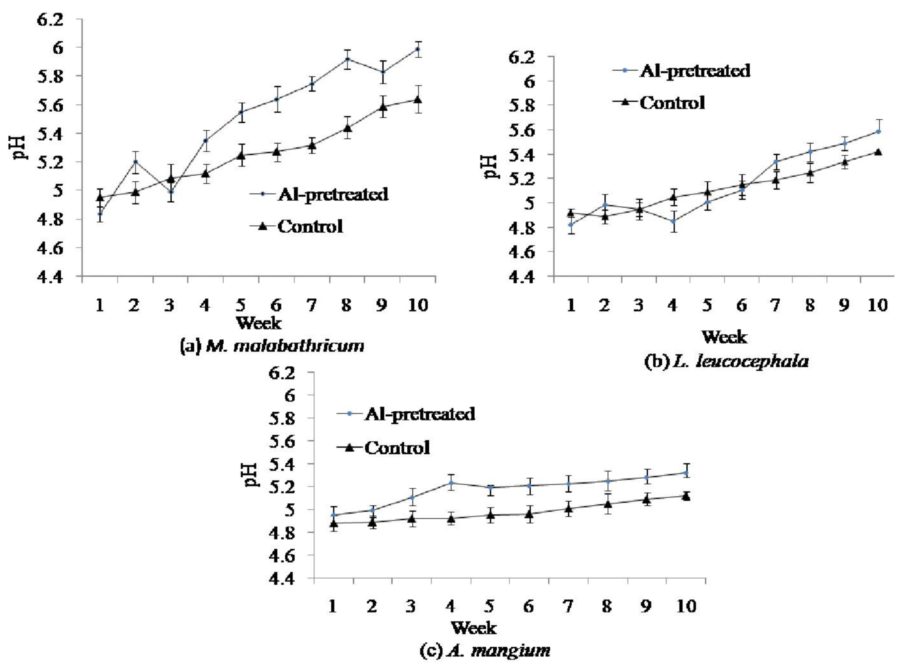

Fig. 8: Soil pH changes grown by Al-pretreated and control plants of the species studied. Vertical bars represent $LSD_{p<0.05}$.

4. Discussion

The increase in root penetration probably satisfied the increase in demand for water and nutrients due to the stressed condition of the slope and thereby a higher amount of carbon in the leaf (Abraham *et al.,* 2009). Preti and Giadrossich (2009) in their study implied that higher root length helping in reinforcing soil, resisting soil erosion and increases water uptake to the upper part of the plant. The root length of Al-pretreated *A. mangium* was significantly lower than the control treatment may be due to the limitation of Al ion on the root growth of *A. mangium* in acidic slope as it is sensitive to the acidic condition**.** The root of Al-pretreated *A. mangium* possibly needs more time to release organic acid anions such as citrate, malate or oxalate from the root apices in response to Al-stress and thus, reduce the root elongation (Prasetyo, 2007). The significant effect of pre-aluminum treatment had forced *M. malabathricum* and *L. leucocephala* (except *A. mangium*) in establishing higher root length (Fig. 3) that helps in nutrient and water absorptions, thus improving plant growth as well as better dry weight performance (Fig. 4).

According to Ma et al. (1997), Al-tolerant plants exhibited better dry weight performance than Al-sensitive plants. Therefore, *M. malabathricum* can be regarded as more tolerant towards acidic condition of the slope compared to *L. leucocepahala* and *A. mangium* as it performed the highest values. The contrary result shown by shoot dry weight of Al-pretreated plants of all species may be due to the early Al-stressed condition which contributed to these species to accumulate the Al in their shoot. As a result, the toxic Al in the shoot might slow down the growth of shoot. In addition, the result behind of the low performance of *A. mangium* was perhaps related to the inhibition of the root elongation by Al-stress (Kikui *et al*., 2005). This result showed good performance of the two species (*M. malabathricum* and *L. leucocephala*) on acidic slope condition, especially on pre-Al treatment plants.

The good performance in photosynthetic rate shown by Al-pretreated species (Fig. 5) as compared to the control is similar to the finding of Hamlyn (1998) who reported that pre-treatment maize has increased the chlorophyll pigment to increase the photosynthetic rate during the acidic stress condition, implying acidic tolerance mechanism of the species. Furthermore, among the Al-pretreated species, *M. malabathricum* exhibited the highest photosynthetic rate, followed by *L. leucocephala* and *A. mangium*. The results indicated that the Al-pretreated *M. malabathricum* increased the photosynthetic rate as a tolerance mechanism towards acidity. This promising characteristic had set *M. malabathricum* apart from the other two species as a potential acidic slope plant. In addition, a higher root length in Al-pretreated *M. malabathricum* might influence in higher potassium uptake which was essential in chlorophyll formation. Hence, this will give rise to the chlorophyll content which led to high photosynthetic rate (Ainsworth and Rogers, 2007). Further, the slope position which is a morning sun slope maximized the sunlight received by those species thus maximizing the photosynthetic activity as well. The species with higher photosynthetic rates indicated that they are more efficient in utilizing light for enhancing growth and are more likely to grow faster, an essential characteristic for a slope colonizer.

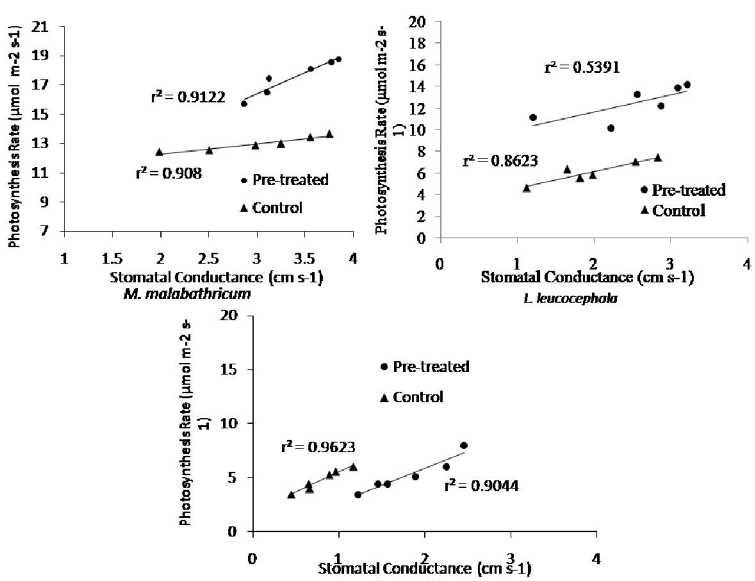

Fig. 9: Relationship between stomatal conductance and photosynthetic rate.

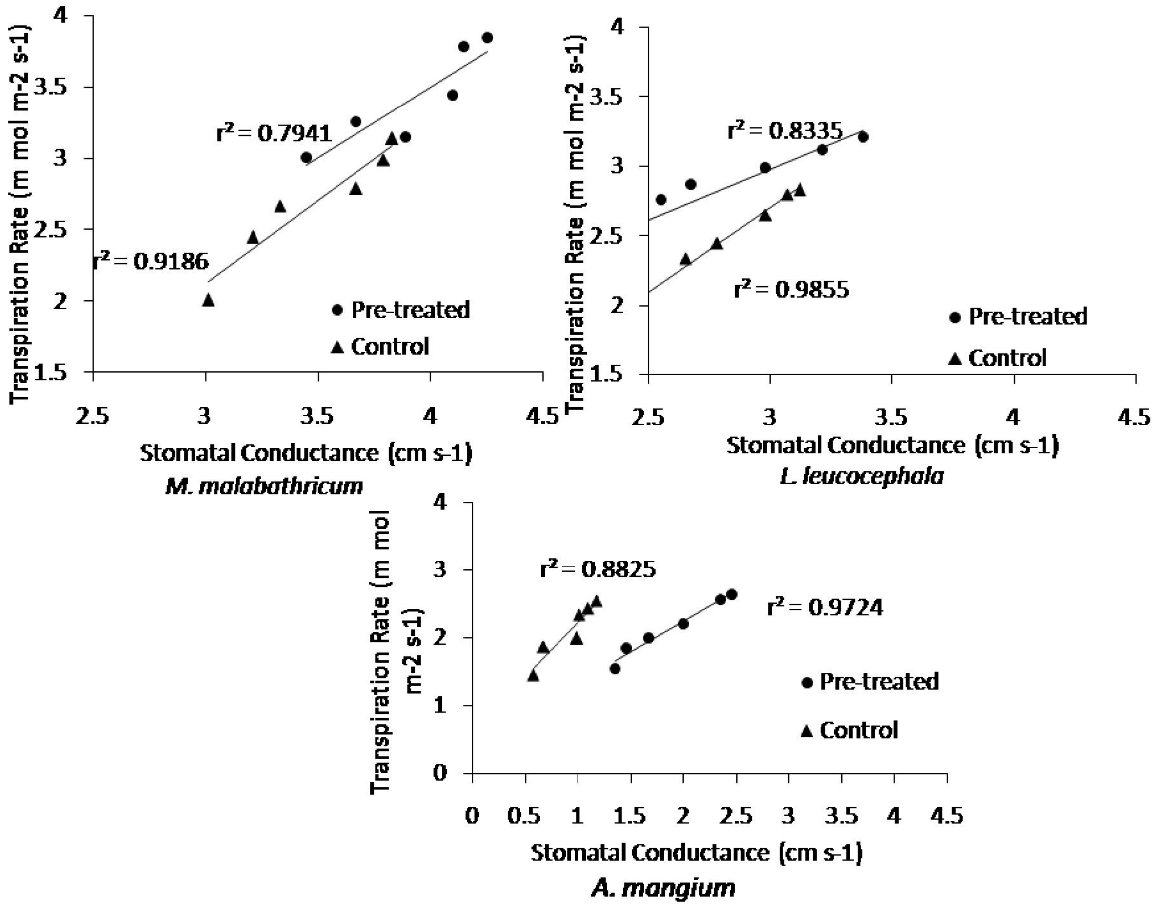

Fig. 10: Relationship between stomatal conductance and transpiration rate.

In addition, the highest transpiration rate (Fig. 5) shown by *M. malabathricum*, followed by *L. leucocephala* and *A. mangium* in both treatments could be attributed to the maximal root system, thus, enhanced the water absorption capacity of the Al-pretreated species as an adaptation towards acidity (Eleftheriou *et al*., 1993). Moreover, it has been shown that 99% of water is lost to transpiration and only 1% will be evaporated. Therefore, besides being an aluminum tolerant, higher transpiration rate is also can be regarded as an essential criterion for a potential acidic slope plant. As a result, the slope would be drier and ultimately in stable condition. This water cycle system is also imperative to the slope condition in order to avoid the soil from being saturated. As *M. malabathricum* was noted to have the highest transpiration rate compared to the other species in both treatments, this species could be considered to fulfill the acidic slope plant criteria. Also, in the case of Al-pretreated *M. malabathricum* and *L. leucocephala*, high leaf area as well as stomatal opening may contribute to high transpiration rate, hence in favor to reduce the water saturation level of the slope.

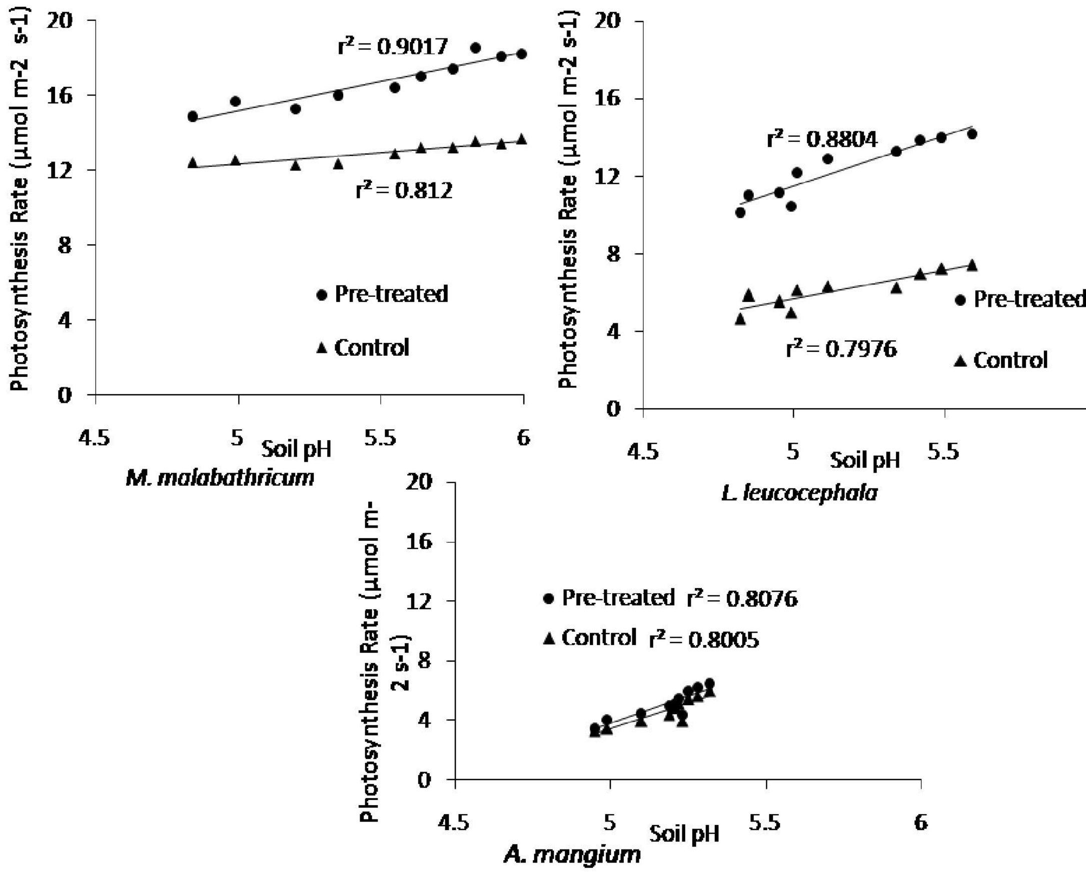

Fig. 11: Relationship between soil pH and photosynthetic rate in Al-pretreated and control.

The stomatal conductance operates in the apparent contradiction way due to the minimized water loss relative to the amount of CO_2 uptake. The results also indicate that the low rate of stomatal conductance can be one of the mechanisms to conserve water, another significant criterion of a slope plant. However, the tolerance mechanisms in stomatal conductance of different species are likely depending on the particular physiology and ecology situation (Heterington and Woodward, 2003). For example, longer root lengths of *M. malabathricum* in both treatments imply the ability of the species to absorb water from the soil. As a mechanism to maintain tugor potential to a substantial level through osmotic adjustment, *M. malabathricum* increases the stomatal conductance to release the excessive water from the plant to the air. This criterion is also regarded as a tolerance mechanism of this particular species to maintain itself as pioneer vegetation on the acidic slope.

Stomatal conductance and photosynthetic rate of all species appeared to be highly correlated in both treatments but with varying degrees (Fig. 9). The stomatal opening in both *L. leucocephala* and *M. malabathricum* is at a similar range in which the Al-pretreated plants showed a higher photosynthetic rate, implying that the pre-aluminum treatment give more positive effect on the growth of the species studied. In addition, the Al-pretreated plants tend to use internal carbon in order to increase the photosynthetic rate at the lower range of stomatal conductance. According to Jarvis and Davies (1997), the increase in net photosynthesis is positively correlated to the increment in stomatal conductance. However, both treatments of *A. mangium* showed the contrary results, indicating the Al-treatment did not give any significant effect on photosynthetic rate. This may be due to the control plants tends to close stomata completely to reduce the water loss and in fact that the closure of stomata is a very effective protection for plants exposed to severe stress levels. In a conclusion, the Al-pretreated *M. malabathricum* showed the highest stomatal conductance and photosynthetic rate in both treatments.

Similar trend was observed in the correlation between stomatal conductance and transpiration rate, both parameters were directly related (Fig. 10). At the same range of stomatal conductance, the transpiration rate of Al-pretreated *M. malabathricum* and *L. leucocephala* exhibited higher values, indicating that the pre-aluminum treatment would enhanced the water absorption capacity. Therefore, the stomatal conductance of both species increased in order to release abundant water, thus increasing the transpiration rate as well. While, both treatments of *A. mangium* had lower transpiration rates regardless the stomatal conductance values. Low transpiration rate observed in control was due to the adaptation mechanism in order to conserve more water.

The photosynthetic rates of all species increased with increasing soil pH (Fig. 11). This soil pH increment is may be due to the acidic material uptake (Aluminum) by the plants, thus, improve the soil organic matter as well as increasing the nutrients for example, P and K that helps in the photosynthesis process. In addition, to undergo an acid soil rehabilitation process, all species had to increase their soil pH by setting up several tolerance mechanisms, for example by increasing the soil pH around the root apices (Kochian *et al*., 2004). Recently, Watanabe *et al.* (2008) found that roots of *M. malabathricum* exuded large amount of mucilage and the root mucilage is generally known to immobilize metal cation such as Al in the rhizosphere. However, his studies indicated that the unique root mucilage (higher charge density) of *M. malabathricum* facilitates Al uptake in this species by absorbing more negatively charged anion than positively charged cation to maintain the root's surface pH of above 5.0. This root-mediated mechanism was prominent in increasing the soil pH around the rhizospehere. Besides, Watanabe *et al.* (2000) reported that, lowering soil pH was responsible to inhibit the root growth. However, Vitorello *et al.* (2005) in his previous studies found that, some species will protect themselves from Al (main cause of acidity) by increasing the pH around the root apices. Following that, the root length increases in order to get some nutrient for their growth as the soil pH increase. As the availability of essential nutrients for the process become higher, the photosynthetic rate will also be increased. However, similar photosynthetic rate obtained in *A. mangium*, indicating no significant effect of the pre-aluminum treatment on the relationship of both parameters studied. Among the treatment studied, Al-pretreated *M. malabathricum* exhibited the highest increment in soil pH and photosynthetic rate.

LAI of the Al-pretreated plants except *A. mangium* were significantly higher compared to control. This result may due to the excessive aluminum that disturbed the root mineral uptake of the species and cause the plant's growth inhibition. The Al-pretreated *M. malabathricum* showed the best performance than Al-pretreated *L. leucocephala* in parameter studied and these results obtained in the current experiment were depending on the level of the aluminum accumulation characteristics of both species. In the previous study by Watanabe (2001), he concluded that Al plays some physiological roles in *M. malabathricum* roots whereby it was transferred to the leaves as a waste material. This causes *M. malabathricum* to create tolerance mechanism by increasing leaf area to accumulate more aluminum in its leaves and then being removed from the plant when the leaves drop.

Al concentration in the leaves of all Al-pretreated species was higher than the control at the beginning of the experiment due to the pre-existence of Al during germination (pre-aluminum treatment). The early exposure also could be an advantage to the Al-pretreated species to easily adapt on the harsh condition of the slope compared to the controlled species which need some time to recover from the extreme condition. The control species began to accumulate Al in their leaves as the Al concentration increased rapidly at the end of experiment. According to the previous experiment by Jansen *et al*. (2002), the mean content of Al in the leaves of plants was 200 ppm. In the current experiment, at the end of observation, the leaves of both Al-pretreated and control species absorb two to ten times than that of Jansen's finding. In addition, another study by Jansen *et al*., (2003) reported that Al accumulation in the leaves was one of the mechanisms to resist Al stress. Thus, the results indicate that all species studied were accumulating the Al in their leaves as a tolerance mechanism towards high Al stress on acidic slope.

The plants which exhibit Al concentration more than 1000 ppm in their leaves are reportedly classified as an Al accumulator (Jansen *et al*., 2002). Hence, as the leaves of control *L. leucocephala* and *M. malabathricum* accumulate more than 1000 ppm of Al, the species could be classified as Al accumulators. On the other hand, *A. mangium* has only accumulated about 400 ppm, indicating that this species is a non-accumulator. Contrary, Ma *et al*. (2002) from their previous experiment found that *A. mangium* was an Al accumulator plant. The different result obtained may be due to the different condition of exposing the *A. mangium* to the high Al concentration. One explanation could be that the experiment done by Ma *et al.* (2002) was in the laboratory, whereby in this experiment, *A. mangium* was planted on the real condition of acidic slope which possibly influenced the result. Therefore, *A. mangium* has not shown a prominent criterion as a potential slope plant.

The decreasing in the soil pH on both control and Al-pretreated (Fig. 8) plots probably due to the low progress of both Al-pretreated species in accumulating Al in their leaves during adaptation phase. The soil pH was higher in all plots grown by Al-pretreated species implying that Al pre-existence had forced the species to change their physiological parameters, for example by producing higher root length that helps in improving soil organic matter and later rehabilitate the acidic slope. Although the acidic slope was not rehabilitating completely in this experiment, it was hypothesized that the soil pH will increase in time and ultimately would reach the optimum soil pH for plant growth. According to Dobermann and Fairhust (2000), if the soil solution was too acidic, the availability of N, P and K decreased and affected the plant growth.

In conclusion, the Al-pretreated species especially *M. malabathricum* and *L. leucocephala* exhibited better physiological performance. The treated plants exhibited several tolerance mechanisms including the root length enhancement, partial stomatal closure, and high LAI. The interaction and compilation of all tolerance mechanisms contribute to the rehabilitation of the acidic soil. In addition, amongst the species studied, *M. malabathricum* exhibits the best potential slope species, regarded as a strong Al-accumulator with high tolerance mechanisms.

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Corresponding Author:

Mohammed Saifuddin
Institute of Biological Sciences, Faculty of Science, University of Malaya, 50603
Kuala Lumpur, Malaysia.
Email: saifuddin@siswa.um.edu.my

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