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Physiological Responses and Root Profiles of *Melastoma malabathricum* Grown with Food Waste Compost and Lime as Soil Amendments in Acidic Soil Condition

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ABSTRACT

Soil acidification prevents the elongation of roots, which is one of the major constraints to crop productivity. Proper acidic soil amelioration can improve soil fertility, resulting in an increase in plant physiological processes and the survival of the plants. The interaction of physiological responses and root profiles in *Melastoma malabathricum* as a result of soil amelioration using food waste compost, liming, and a combination of food waste compost and liming when grown in acidic soil conditions was assessed. The resulting plants exhibited an outstanding leaf area index, relative chlorophyll content, photosynthetic rate and water use efficiency in food waste compost treatment. Similarly, the plants also showed the highest root volume and diameter. The results implied that the application of soil amendment, specifically food waste compost towards acidic soil was able to enhance plant growth through better gas exchange and root morphology. In addition, a positive correlation was observed between root diameter and root volume with the physiological responses, indicating that soil amendments assisted plants in getting the nutrients necessary for gas exchange, hence influencing the plant roots. In conclusion, the use of food waste compost alone was deemed adequate as it showed good effects on plant physiological performances as well as root profiles. Hence, the preliminary results of this study highlight the potential use of food waste compost as a promising solution to support the growth and development of plants, especially those grown under acidic soil conditions.

Keywords: Plant physiology; root profiling; soil acidity; soil amendment; woody shrubs.

INTRODUCTION

Infertile soil caused by soil acidification has become one of the primary constraints to plant growth and development. The productivity of a plant and soil fertility are adversely affected by acidic soil (Osuji and Nwoye, 2007). The shallow root produced with the poor performances of the plants has ramifications on nutrient acquisition (Opala, 2011), plant establishment and survival (Fekadu et al., 2018). Amongst the species, *Melastoma malabathricum* has gained significant research interest in tropical countries like Malaysia, due to its maximum tolerance for acidic soil, as measured by plant morphological parameters and photosynthetic capacity (Watanabe and Osaki, 2002; Normaniza and Rohailah, 2011; Dorairaj et al., 2020). This woody shrub plant species, which is a member of the Melastomataceae family, has been documented

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as growing wild in the Indian Ocean Islands, throughout South and Southeast Asia, China, Taiwan, Australia, and the South Pacific Ocean (Wong, 2008).

Liming has become a common practice used to help reduce soil acidity (Opala, 2011). Liming is widely used and has been found to be successful in increasing soil pH and alleviating acidity related constraints on crop production by changing the soil chemical and physical properties. However, the expensive cost of lime and its enormous volume necessary to accomplish stability has made this method not cost effective in many developing and developed countries. Furthermore, over liming can create deficiencies of micronutrients (Fageria and Baligar, 2008). Apart from that, it has been reported that other approach such as compost has the capability to be a practical soil improver to increase soil fertility (Adugna, 2016; Viaene et al., 2016). Compost supplies nutrients and organic matters as it contains beneficial microbes and sustains their life in soil (Sæbø and Ferrini, 2006). Wong and Swift (2001) reported that compost made from municipal and plant waste was capable of treating acid soils, increasing the soil pH and improving growing conditions for the plants. The strong root growth in compost-treated soil means that there are more soil microorganisms to interact with root, thus affecting the root growth. Food waste is commonly used as a composting material as it is high in organic matter and low in heavy metals. It contains plenty of polysaccharides sourced from fruits and vegetables, making it an excellent carbon and energy source for microorganisms (Lee et al., 2004). Co-composting was proposed as a technique for waste recycling (Külcü and Yaldiz, 2014). Thus, combined treatment between compost and lime was proposed in this research. Therefore, this study aimed to evaluate the interaction among physiological parameters and root profiles of *M. malabathricum* as affected by food waste compost, liming and the combined treatment of liming and food waste compost when grown in acidic soil condition.

MATERIALS AND METHODS

Site description and plant materials

This study was conducted in a glasshouse from August 2019 to February 2020 at Rimba Ilmu, Institute of Biological Sciences, Universiti Malaya, Kuala Lumpur, Malaysia (3º7'52.1076"N, 101º39'25.218"E). The maximum of Photosynthetically Active Radiation (PAR) was 2000 µE mol/m^2/s, relative humidity (RH) of 65 to 90% and atmospheric temperature was between 25 to 28°C. All the *M. malabathricum* seedlings were obtained from the nursery at Sungai Buloh, Selangor, Malaysia. The average age and height of all plants were about 1 to 2 months and 10 cm, respectively. The plants were observed bimonthly beginning 14 days after transplanting (DAT), and data were collected on a monthly basis for 6 months.

Experimental design and treatments

Two soil amendments were used for this experiment which were food waste compost and ground magnesium liming. This study comprised four treatments which were control (Q), ground magnesium liming (L), food waste compost (C), and combination of ground magnesium liming and food waste compost (LC). The experiment was laid out in a Complete Randomized Design (CRD), with six replications. All the plants were grown in a polybag with a height of 26 cm and a diameter of 20 cm. An 8164 cm^3 of acidic sandy loam soil was filled in a polybag and underwent an incubation period of 2 weeks before planting. All of the plants were watered sufficiently every morning during the experiment to keep them turgid and avoid water stress. Compost used in this study was obtained from the UM ZWC (Universiti Malaya, Malaysia), which was made from food waste generated on the campus. The physical properties of the soils and the amendments used in this study were as listed in Table 1, and the nutrient content of the food waste compost was as described by Abdullah et al. (2021).

Table 1. Physical properties of soil and the amendments used in the study

Properties	Soil	Lime	Food Waste Compost
pH	3.9	9.74	6.6
EC (dS/M)	0.1	-	2.84
Texture/Appearance	Sandy loam	White powder	Blackish brown
Bulk density (g/cm^3)	1.3	-	-

Leaf area index (LAI)

A ceptometer (AccuPAR LP-80 Decagon Devices, Inc, USA) was used to determine the leaf area index at the beginning and end of the study. A long rod (1 m) with 80 sensors separated into eight segments was used to take the average readings per plant, above and below the plant.

Relative chlorophyll content

The relative chlorophyll content was determined using a chlorophyll meter (SPAD-502, Minolta, Japan). The measurements were conducted from 1100 to 1400 h, when the photosynthetic process was at its peak. Three randomly selected plants from each of the replications had leaves sampled from nodal positions two, three, and four below the apex on the main axis. The average was calculated after taking triplicate values of relative chlorophyll content.

Physiological responses

Physiological responses such as the photosynthetic rate, stomatal conductance, transpiration rate and water use efficiency of the plants studied were measured using a portable photosynthesis system (LiCor-6400; LiCor Inc., USA) equipped with an LED source leaf chamber. The readings were taken between 0900 h to 1130 h, during which the optimum photosynthesis activity of *M. malabathricum* occurs (Aimee and Normaniza, 2014). During the measurements, the leaf temperature was set up at a similar temperature as the ambient value, and the ambient CO_2 concentration in the cuvette was held at 400 µmol/mol. The same leaves used for relative chlorophyll content were chosen for every treatment. Six technical replications were logged and recorded for each treatment.

Root profiles

The root profiles were analysed using a root scanner (WinRHIZO Pro v. 2008a, Regent Instruments Inc., Canada) after six months of planting period. The harvested roots were removed from the soil and rinsed with tap water using a 2.0 mm sieve. Triplicate readings for root length, root volume and root diameter were measured to obtain the average readings. The result obtained from the analysis, such as the root length was then used to determine the total root length density using the following formula:

$$\text{Root length density (cm/m}^3\text{)} = \text{Total root length/soil volume}$$

Statistical analysis

The data were analysed using IBM SPSS Statistic 25 software (IBM Corporation, Armonk, NY, USA). A one-way ANOVA was applied to evaluate the significant differences in the treatments and means were tested by Tukey's test at a 5% level of confidence. Differences between initial and final readings were analysed using a t-test. The relationship between the parameters were determined using a Pearson correlation at $p \leq 0.05$ and 0.01.

RESULTS AND DISCUSSION

Leaf area index and relative chlorophyll content

There were significant differences in leaf area index between final and initial planting period (Table 2). A significant increment was observed in the compost treatment and the lowest was recorded in control plant. *M. malabathricum* grown in compost showed the highest increase for leaf area index value, followed by combined treatments.

Table 2. Leaf area index and relative chlorophyll content among treatments

Treatment	Leaf area index		Relative chlorophyll content	
	14 DAT	180 DAT	14 DAT	180 DAT
Control	0.17^{a}	0.30^{a*}	51.57^{c}	39.10^{c*}
Liming	0.09^{b}	0.39^{a}	54.80^{b}	42.07^{b*}
Compost	0.06^{b}	0.55^{a}	62.40^{a}	45.47^{a*}
Liming+Compost	0.08^{b}	0.48^{a*}	52.40^{c}	41.33^{bc*}

*Significant at $p \leq 0.05$ between initial and final planting period (t-test); Means followed by the same letter within column are not significantly different amongst treatments by Tukey's test at $p \leq 0.05$.

Food waste compost application helps plants by supplying nitrogen and phosphorus that benefit the plant growth, as well as with higher base saturation and cation exchange capacity (Abdullah et al., 2021). The leaf area development could primarily be controlled by the amount of N available for plant growth resulted from a good root system (Hirose et al., 1997). This study showed that the lowest increment at the final stage can be seen in the control treatment. This may be due to the mechanism of adaptation towards acidity in *M. malabathricum* that helps plants to respond well in the parameter studied (Watanabe and Osaki, 2002).

The values of relative chlorophyll content significantly decreased in all soil treatments (Table 2). The relative chlorophyll content for the *M. malabathricum* grown on compost amendment was found to be the highest at the final planting stage compared to other treatments, with relative chlorophyll content of 16.3% higher than the control. This was followed with liming and the combined treatment, with 7.6% and 5.7% of increase, respectively. The results showed that the relative chlorophyll content was significantly affected by the soil amendments. The increased leaf pigment content such as carotenoids and chlorophylls was most likely owing to an improved plant nutritional condition (Libutti et al., 2020). Compost treatment showed the highest in relative chlorophyll content because of the lowest organic acids and carbon dioxide from the compost degradation process which play a role in enhancing the availability of plant nutrient content such as Mg that is involved in chlorophyll synthesis, thus increases the photosynthetic rate as well (Hasan et al., 2014). The availability of N in the soil contributed from the food waste compost (Abdullah et al., 2021) might affect the parameter studied as it is often linked to the chlorophyll content. N is the primary yield component and is found in chlorophyll molecules, proteins, amino acids, nucleic acids (RNA and DNA), nucleotides, phosphotides, alkaloids, enzymes, coenzymes, hormones and vitamins (Libutti et al., 2020).

Physiological responses

The photosynthetic rate were reduced in all treatments except for compost (Table 3). The photosynthetic rate of *M. malabathricum* grown on liming treatment (L) was observed to be significantly decreased (48.20%) throughout the planting period. In contrast, the photosynthetic rate of plants grown on compost (C) was observed to increase by 14.15% and was significantly the highest rate compared to other treatments at the final planting stage. The higher photosynthetic rate indicated that the plant was capable of utilising light for their growth (Saifuddin and Normaniza, 2012).

Table 3. Mean values of analysis of variance of photosynthetic rate (A), stomatal conductance (gs), transpiration rate (E) and Water Use Efficiency (WUE) among treatments at initial and final planting stage

Treatment	Initial planting stage (14 DAT)				Final planting stage (180 DAT)			
	A (µmol/ m^2/s)	gs (mol/ m^2/s)	E (mmol/ m^2/s)	WUE	A (µmol/ m^2/s)	gs (mol/ m^2/s)	E (mmol/ m^2/s)	WUE
Control	7.54^{c}	0.27^{c}	2.62^{b}	2.88^{c}	4.07^{d*}	0.04^{a*}	1.43^{a}	2.84^{b}
Liming	11.14^{a}	0.29^{b}	2.65^{a}	4.21^{a}	5.77^{c*}	0.06^{a*}	1.88^{a*}	3.07^{b}
Compost	9.33^{b}	0.30^{a}	2.63^{b}	3.56^{b}	10.65^{a}	0.05^{a*}	1.65^{a*}	6.46^{a*}
Liming+Compost	9.89^{b}	0.27^{d}	2.62^{b}	3.77^{b}	8.37^{b*}	0.06^{a*}	2.05^{a*}	4.08^{ab}

* Significant at $p \leq 0.05$ between initial and final planting period (t-test); Means followed by the same letter within column are not significantly different amongst treatments by Tukey's test at $p \leq 0.05$.

In general, the photosynthetic rate was affected by the amount of chlorophyll in the leaf. In addition, the release of nutrient content from the compost directly to the plant might contribute to the increase in photosynthetic rate (Martínez and Guiamet, 2004). Stomatal conductance was observed to significantly decrease in all soil treatments after 6 months of treatment. At the final planting stage, *M. malabathricum* grown with liming (L) and the combined treatment (LC) recorded the highest stomatal conductance, where both resulted in 50% increment compared to control. The same trend was observed in the transpiration rate, where it decreased significantly throughout the observation for all soil treatments. According to Maiti et al. (2016), transpiration regulates the water balance in plants and is influenced indirectly by the environmental factors such as low pH conditions, through the effects of stomatal opening. A higher reduction in transpiration rate indicated that the treatments increased the plant stomatal resistance mechanism to reduce water loss but maintain the photosynthetic rate.

Root profiles

The root length of *M. malabathricum* after 6 months of growth was depicted in Table 4. In compost (C) treatment, the root length was 23.6% lower than control. In contrast, the application of liming (L) and combined-treated soil (LC) resulted in 51.1% and 10.2% longer root length than control, respectively. This indicated that liming was more effective in promoting the root length in *M. malabathricum* and it worked better in enhancing root elongation compared to compost. Furthermore, liming is also known as a good acidic corrector over the decades, with the ability to ameliorate soil toxicity, thus root mechanisms can work better. Plants grown on control and combined treatments also recorded an increase in both root length and root length density. The mechanical strengthening of the soil by plant roots occurred as a direct result of compost usage (Donn et al., 2014). In addition, previous research has reported that the application of compost could enhance root elongation (Zhang et al., 2014), in contrast to the findings of this study. This implies that root elongation may also depend on the quality and composition of the compost used.

Table 4. Mean values of analysis of variance of root length, root diameter, root volume and root length density among treatments

Treatment	Root length (cm)	Root diameter (cm)	Root volume (cm^3)	RLD (m/m^3)
Control	9.74^{ab}	1.80^{ab}	24.69^{a}	2823.37^{ab}
Liming	14.72^{a}	1.10^{b}	13.07^{a}	4266.76^{a}
Compost	7.88^{b}	2.39^{a}	35.45^{a}	2285.14^{b}
Liming+Compost	10.73^{ab}	1.64^{ab}	23.45^{a}	3109.80^{ab}

*Means followed by the same letter within column are not significantly different by Tukey's test at $p \leq 0.05$; RLD = root length density

The root diameter of *M. malabathricum* grown on compost (C) treatment was significantly higher compared to other treatments. On the other hand, the root diameter decreased by 8.9% and 38.9%, respectively, in combined-treated soil (LC) and liming (L). Similar trends were shown in both root diameter and root volume. However, root volume was not significantly affected by all soil treatments. These observations implied that by applying compost as soil amendment, it might increase the matrix of soil-root, which subsequently elevate the potency of the plants in absorbing an adequate amount of water. Higher root volume and root diameter indicated that plants grown on compost-treated soil showed good absorbance of minerals (Adugna, 2016). The increase in root diameter can also trigger the shear strength of the root-soil composite, hence providing a better capacity to handle soil surface erosion and runoff.

Correlation analysis between parameters

The results of the correlation analysis were presented in Table 5. In this study, there was a strong positive correlation ($p < 0.05$) between the root diameter and root volume of plants supplied with compost (C), liming (L) and combined treatment (LC). This result showed that in these treatments, as the root diameter of *M. malabathricum* grown in acidic soil increased, root volume also increased. Soil amendments such as liming (Meharg and Killham, 1990) and compost were able to increase the volume of root, hence improve C input to soil and enhance the available surface for gas exchange and interception of light (Alluvione et al., 2010; Rehman et al., 2016).

A high positive correlation was observed between the root diameter and rate of photosynthesis ($p \leq 0.01$) in combined treatment (LC). In addition, a positive correlation was also found between root diameter with the stomatal conductance in compost (C) and liming (L) treatments. Liming treatment also resulted in a positive correlation between the root diameter and transpiration rate. These indicated that root diameter is associated with the rate of photosynthesis, stomatal conductance and transpiration rate, implying that the increase in root diameter could increase the plant physiological performance by enhancing water and nutrient uptake from the soil (Parton et al., 1987; Biondini, 2001).

A strong positive correlation was observed between the root volume with the rate of photosynthesis in combined treatment (LC), with stomatal conductance in liming (L) and compost (C) and with the transpiration rate in liming (L). These indicated that soil amendments help plants in acquiring the nutrients necessary for gas exchange capability (Johnson et al., 2009) by improving C fixation (Hernandez et al., 2017), thus influences root physiology and morphology.

Table 5. Pearson's correlation coefficient between physiological performance and root profiles of *M. malabathricum* grown compost, liming and combined treatment (LC) as soil amendment

	Compost (C)							Liming (L)							Liming + Compost (LC)						
	Physiological response				Root profiles			Physiological response				Root profiles			Physiological response				Root profiles		
	A	gs	E	WUE	RD	RV	RLD	A	gs	E	WUE	RD	RV	RLD	A	gs	E	WUE	RD	RV	RLD
A	1.00	-0.21	0.35	.962**	-0.16	-0.10	0.34	1.00							1.00	0.23	0.33	0.74	.830*	0.70	0.32
gs		1.00	0.77	-0.44	0.66	0.54	-.946**	-.998**	1.00							1.00	.974**	-0.48	0.39	0.25	-0.03
E			1.00	0.08	0.35	0.24	-0.73	-.998**	1.000**	1.00							1.00	-0.39	0.47	0.35	0.10
WUE				1.00	-0.27	-0.18	0.57	.997**	-1.000**	-1.000**	1.00							1.00	0.48	0.43	0.25
RD					1.00	.986**	-0.68	-0.75	0.73	0.73	-0.73	1.00							1.00	.929**	0.57
RV						1.00	-0.55	-0.68	0.67	0.67	-0.67	.983**	1.00							1.00	.836*
RLD							1.00	0.76	-0.71	-0.72	0.71	-0.71	-0.57	1.00							1.00

*. Correlation is significant at the 0.05 level (2-tailed); **. Correlation is significant at the 0.01 level (2-tailed); A=photosynthetic rate; gs= stomatal conductance; E= transpiration rate; WUE= water use efficiency; RD= root diameter; RV= root volume; RLD= root length density.

With regards to root length density (RLD), a strong positive correlation was found between RLD with the rate of photosynthesis in lime treatment (L). RLD also showed a positive correlation with water use efficiency (WUE) in both liming (L) and compost (C). However, root length density showed a significantly negative correlation with stomatal conductance in compost treatment. This indicated that the closure of stomata reduced water loss, thus maintaining water balance and plant turgidity. Hence, the plant could be able to access water from wider and deeper areas by its extensive root system (Amede and Schubert, 2003).

CONCLUSIONS

Based on the results, *M. malabathricum* grown with food waste compost (C) showed significantly higher rate of photosynthesis and WUE compared to other treatments. Food waste compost also stimulated root diameter and root volume, where these values were found to be higher than other treatments. Correlation analysis showed that the root diameter and root volume of *M. malabathricum* grown on combined treated soil (LC), compost (C) and liming (L) were positively correlated with the physiological responses. Thus, this study revealed the vast benefits of soil amendments that can contribute towards enhancing the growth and survival of *M. malabathricum* grown on tropical acidic soil. The results of this study also provide compelling evidence for profiling the plant that can tolerate acidic conditions. Food waste compost was found to be the most effective approach in neutralising soil acidity, resulting in improved physiological performance and better root profiles.

AUTHORS CONTRIBUTION

NO, RA and JSY conceived and designed the work. LSR and SNZO performed the analysis. LSR and NO wrote the paper. NO and LSR checked and approved the submission.

CONFLICT OF INTEREST

The authors declare that they have no competing interests.

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