PHYSIOLOGICAL AND MORPHOLOGICAL RESPONSES OF RUBBER (*Hevea brasiliensis*) RRIM 3001 TO DIFFERENT RATES OF BASALT APPLICATION

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ABSTRACT

Rubber, is one of the main commodity plantation crops in Malaysia that has contributed greatly to the nation economy. Response of rubber tree towards basalt, natural soil amelioration is still unknown. This paper will elaborate the responses of rubber seedlings, RRIM 3001, towards different rates of basalt in terms of growth performance. The treatments were application of 40 g, 80 g, 160 g and 240 g of finely ground basalt on the growth of rubber seedlings. The results showed that application of basalt at a rate of 240 g per plant improved the soil chemical properties as exhibited by the 15% increase in pH, availability of phosphorus by 213%, exchangeable K by 463%, exchangeable Mg by 55% and reduced exchangeable Al by 74%). These changes subsequently enhanced the rubber seedlings growth as observed with increasing plant height and stem girth. Therefore, basalt is a good soil amelioration and functions as a slow release fertilizer for Rengam soil series.

Keywords: *Hevea brasiliensis*, basalt, soil amelioration, growth, plant nutrition, soil nutrition

INTRODUCTION

Rubber was once well-known as Malaysia 'Sun Rise Crop' which originated from Amazon Basin. *Hevea brasiliensis* has contributed much to the economy as this country is the third largest producer of natural rubber and the fifth in terms of consumption of natural rubber in the world (Shafar et al. 2012). To fulfil the demand for latex and timber, the Malaysian Rubber Board (MRB) has conducted research to produce rubber trees that can contribute extraordinary return of latex and timber which resulted in the introduction of RRIM 3001 clone. This clone has several important features which are vigorous in growth and provide greater yield thus has been assigned a new name, Clone 1 Malaysia (Borneo Post Online 2011).

Lack of suitable areas has caused the rubber trees to be planted in problem soil and dry areas (Shafar et al. 2011). More than 50% of the soils in Malaysia were classified as Ultisol and Oxisol. These types of soils are known as highly weathered which has low pH and low fertility (Shamshuddin and Fauziah 2010a). Therefore, a lot of agriculture input such as lime, fertilizer and organic materials are needed to improve the soil fertility and productivity. According to RISDA (2008), the proportion of fertilizer cost can reach as much as 40% of the total maintenance cost. Both the quantity and the composition of latex produced by the tree can be affected by the soil nutrient status and fertilizer application (Noordin 1984).

Improving soil fertility using basalt is a new practice in Malaysia. Recent work on using basalt from Australia as soil amelioration has been reported (Shamshuddin et al. 2016, Panhwar et al. 2016, Shazana et al. 2013, Anda 2006). In Peninsular Malaysia, basalt can be found in two places, Segamat and Kuantan (Gobbett 1972). Only basalt in Segamat has been mined and used; mainly for soil construction. Basalt from Segamat mainly consists of SiO_2 (47.74 %), MgO (10.59 %), CaO (11.96 %), K_2O (3.78 %), P_2O_5 (0.44 %), Na_2O (1.31 %) and others (Gobbett and Hutchison 1973). This experiment has been carried out using Segamat basalt to explore the potential of its usage as soil amelioration

MATERIALS AND METHODS

Soil type and planting materials

Soil used in this experiment was Rengam Series red variant; fine, clayey, kaolinitic, isohyperthermic, Typic Kandiudult (Soil Survey Staff 2014). Rubber seedlings from RRIM 3001 clone at the age of 3 months with two whorl leaves were used in this experiment. Plants at this age are usually used for planting in the field. In this experiment, seedlings were transplanted into bigger polybag (20 inch x 20 inch) which provided adequate amount of soil volume for root growth. The experimental design used was Completely Randomized Design (CRD) with five treatments and six replications. Soils were subjected to different rates of ground basalt containing 40 g, 80 g, 160 g and 240 g per polybag (0, 5, 10, 20 and 30 tonnes/ha).

Basalt incorporation and fertilizer programme

For application methods, finely ground basalt (less than 0.01mm in size) was sieved through 0.1 mm sieve and mixed with the soil together with 25 g of Christmas Island Rock Phosphate (CIRP) before filling it in polybag. The RISDA 1 compound fertilizer (10.7:16.6:9.5:2.4) at the rate of 37.5 g was applied two months after transplanting.

Growth measurements

The growth parameters of tree such as girth, height and chlorophyll content were measured every month for six months. Data for girth and height were measured using vernier caliper and measuring tape, respectively. During first data collection, one mark was placed at the plant stem 10 cm above the soil surface. Measurement of plant height began from this point until the tip of the plant. Stem girth was also measured at this point. Total chlorophyll content was measured using SPAD meter (Minolta Chlorophyll Meter, SPAD-502).

Biomass production and plant nutrient analysis

After six months, biomass production and nutrient content in leaf tissues (nitrogen, phosphorus, potassium, calcium and magnesium) were determined using a destructive method. Leaves for nutrient analysis were collected first before destructive sampling for the whole plant was carried out. Plant leaves, stem and root were separated and only specific leaves were used for nutrient analysis. Leaf sampling was done according to the foliar sampling method adopted by the Malaysian Rubber Board where four basal leaves from the first sub-terminal whorl were collected as a leaf sample (Noordin 2013, Rubber Research Institute of Malaysia 1990). The leaves were separated from the stems and placed in the forced draft oven at 60ºC for 48 hours and the weight was obtained. The N, P, K Ca and Mg content in leaves was determined. The leaves (0.25 g) were digested in 5 mL of sulfuric acid (H_2SO_4) on hot plate at 450°C in a fume chamber for 7 minutes. Ten mL of hydrogen peroxide (H_2O_2) was then added into the mixture and the heating was continued for another 4 minutes. The solutions were made up to 100 mL with distilled water and filtered with filter paper. N and P content was determined using an auto-analyzer (LACHART Instruments, Model Quickhem IC + FIA 8000 Series) while K level was measured using an atomic absorption spectrophotometer (Perkin Elmer, Model AAS 3110).

Soil analysis

Several chemical properties of the soil were analysed before and after the experiment. Soil samples were air-dried, ground and passed through a 2 mm sieve prior to chemical analyses. Soil pH was determined in water at a ratio of 1: 2.5 (soil/distilled water) using a glass electrode pH meter. Cation exchange capacity (CEC) was determined using 1M NH_4OAc at pH 7 (Thomas 1982). Exchangeable Ca, Mg, K and Na were determined using 1N NH_4Cl (Ross and Ketterings 1995). Exchangeable Al was determined by extracting 5 g of soil with 50 mL of 1M KCl. The mixture was shaken for 30 min and the extracted Al was analyzed using ICP-OES. Available soil P was determined according to Bray and Kurtz method (Bray and Kurtz 1945).

Statistical analysis

Analysis of Variance (ANOVA) on data obtained was performed using Statistical Analysis System (SAS 9.4, SAS Institute, Inc. Cary NC. USA). Least Significant Different (LSD) at 0.05 significant level was employed for means comparison only if F values were found to be significant.

RESULTS AND DISCUSSION

Plant Vegetative Growth Analysis

Plant Height

The result showed that basalt application had a great effect on plant height after six months of application (Figure 1). Treatment 1, without basalt application, showed the highest plant height among the treatments. However, treatment 1 had no significant difference with Treatment 5 (240 g basalt) as both treatments showed similar plant height. Meanwhile, the plant treated with basalt (except Treatment 5) was inhibited or retarded by the presence of basalt after six months of transplanting. This phenomenon was possibly due to nutrient imbalance in the soil where the highest rate showed similar results with control while lower rate gave lower results. Lower rate of amendments applied will result in faster reaction and dissolution in the soil solution. Too rapid dissolution of amendments in the soil solution somehow will result in nutrient imbalance and this will slow down the growth of the plant (Kunes et al. 2007). However, if too much amendments are applied, much more time will be needed for the amendments to dissolve. In certain condition, these amendments in dust or grain form will accumulate and form bigger structure. These caking up amendments will slowly dissolve and require much more time than usual. According to Noordin et al. (1988), the excessive application of fertilizer should be avoided for rubber plant during early planting because it will result in too much increase in vegetative growth in terms of plant height rather than girth, subsequently the plant will be prone to trunk breakage. Too much nutrients in the soil and plant tissue will result imbalance of nutrition, prone to disease, scorching and death (Shafar and Noordin 2011). Regression analysis showed that plant height of rubber grown in polybag exhibited high correlation with the basalt treatment as represented by R^2 (0.95) (Figure 2).

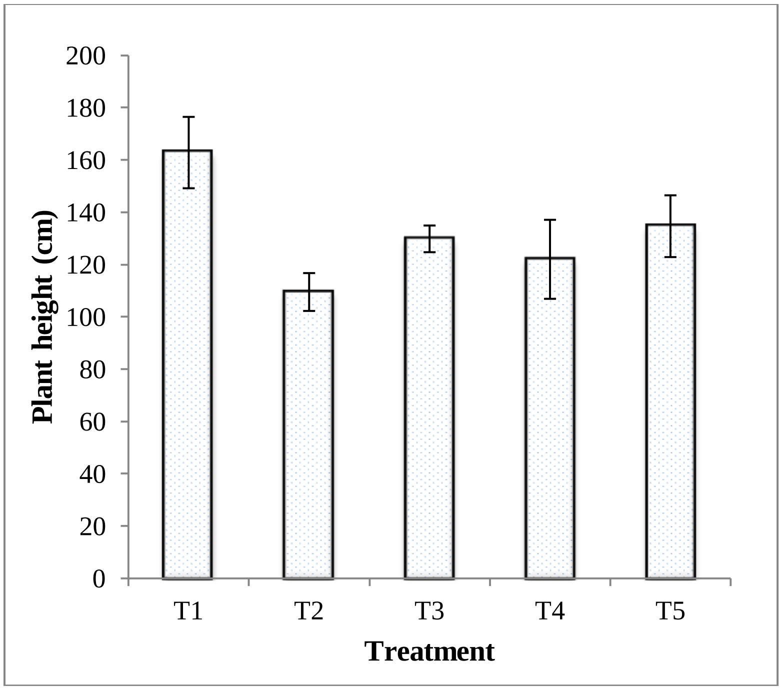

Figure 1. Response of RRIM 3001 plant height to ground basalt treatments for six months.

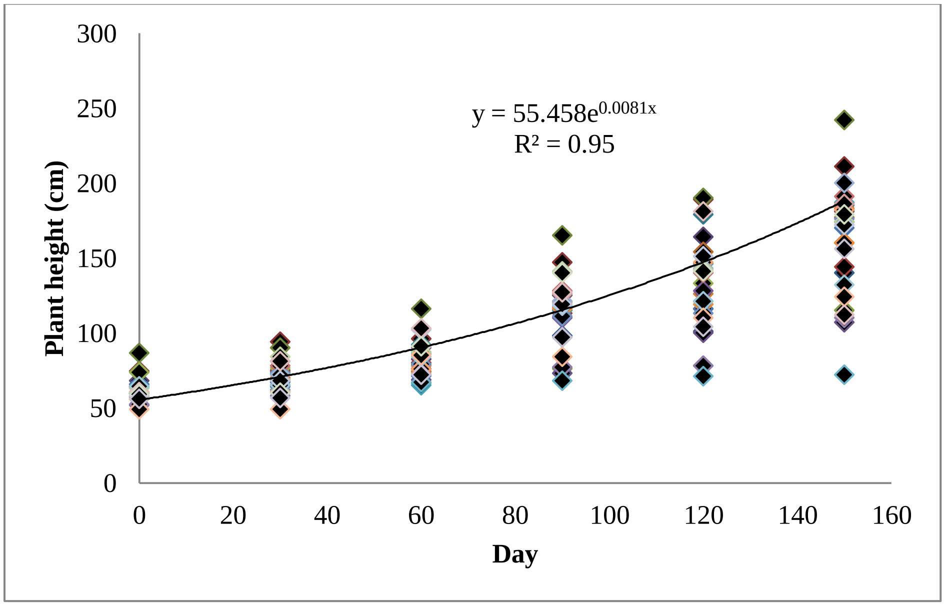

Figure 2. Plant height (cm) for six months

Plant Girth

Naturally, the rubber girth size is a very important indicator or parameter because it determines the yield of the plant in terms of latex flow and its quality (Salisu et al. 2013). In this study, girth of young rubber plant was significantly affected by different rates of ground basalt applied (Figure 3). The result showed that the girth of rubber seedlings with Treatment 1 (0 g basalt) is 49 %, 34%, 25% and 21% higher than Treatment 3 (80 g basalt), Treatment 5 (240 g basalt), Treatment 4 (160 g basalt), and Treatment 2 (40 g basalt), respectively. Growth of plants treated with basalt was relatively slower and it may be due to the change of physical structure in the soil after basalt application. The change in soil physical structure has been observed during mixing basalt with rock phosphate and soil for soil preparation. This might happen due to the fixation of phosphate phenomenon. In highly weathered soils, it is common to have high amount of sesquioxides (Fe and Al oxides) which will absorb the phosphate and make it unavailable for the plant (Noordin, 2013). Excess of unabsorbed phosphate will be in the soil solution and available for the plant uptake. Hence much more phosphate fertilizer is needed to ensure it is available for the plant. Basalt also contains phosphate and hence, application with rock phosphate will increase phosphate availability in soil. Basalt requires longer time to improve the initial vegetative growth of the rubber seedlings. According to Anda et al. (2009), basalt takes time to disintegrate and dissolve completely under condition prevailing in the field. During soil sampling after six months of application, it was observed that there was still accumulating basalt remaining inside the soil. Similarly, high correlation on plant girth with the Rengam soil series was shown represented by R^2 (0.98) (Figure 4).

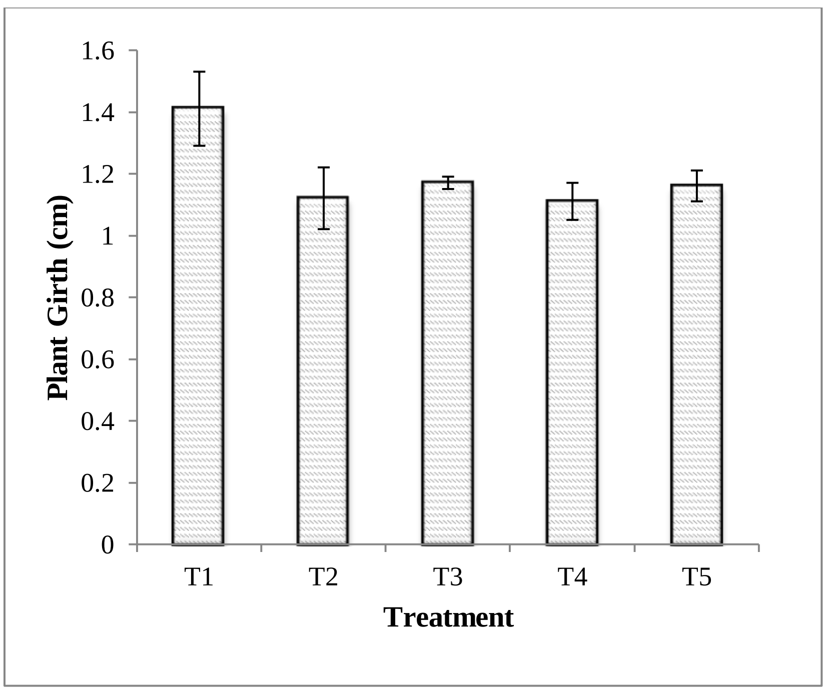

Figure 3. Response of RRIM 3001 plant girth to ground basalt treatments for six months

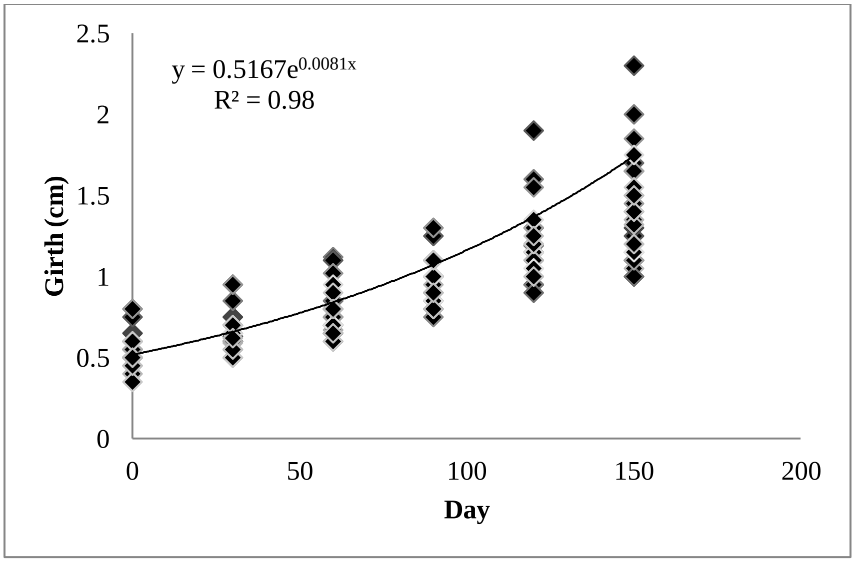

Figure 4. Plant girth (cm) for six months

Plant Chlorophyll Content

Plant chlorophyll content was significantly affected with basalt application after six months of application (Figure 5). Treatment 1 was higher than Treatment 2, Treatment 4, Treatment 5 and Treatment 3 by 20%, 16%, 11% and 5%, respectively. The result also showed that there was no significant difference between Treatment 1 (0 g basalt) and Treatment 3 (80 g basalt). Increasing chlorophyll content results in increasing photosynthesis rate of *Hevea* plant, leading to increased plant growth (Shafar et al. 2011, Shafar et al. 2012). Increase in stomatal conductance leads to increased rate of photosynthesis and higher biomass production (Noorsuhaila et al. 2014).

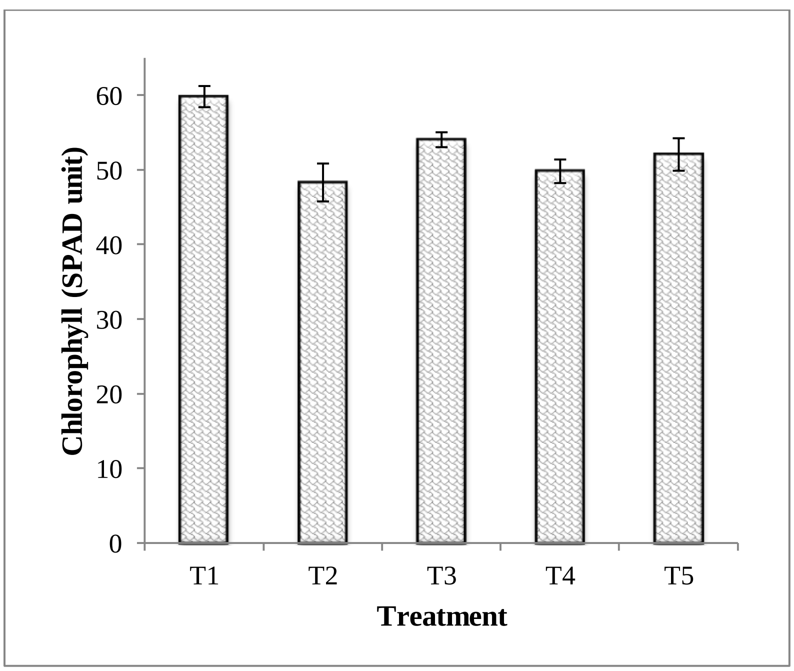

Figure 5. Response of RRIM 3001 chlorophyll content to ground basalt treatments for six months

Dry Weight

Growth of plant was also measured in terms of biomass production (Table 1). There was no significant difference among the treatments in leaf dry weight at $p < 0.05$. Treatment 1 was higher by 23%, 22%, 16% and 2% compared to Treatment 3, Treatment 2, Treatment 4 and Treatment 5, respectively. For stem dry weight, there was also no significant difference among the treatments at $p < 0.05$. Nevertheless, Treatment 3 showed the highest results by 39%, 36%, 9% and 0.04% compared to Treatment 2, Treatment 4, Treatment 1 and Treatment 5, respectively. For root dry weight measurement, there was no significant difference between Treatment 1 (0g basalt), Treatment 5 (240 g basalt) and Treatment 2 (40 g basalt) at $p < 0.05$. However, Treatment 3 (80 g basalt) and Treatment 4 (160 g basalt) was significantly lower than other plant treatments. Treatment 1 was higher than than Treatment 4, Treatment 3, Treatment 2 and Treatment 5 by 84%, 81%, 21% and 4%, respectively. Therefore, Treatment 1 with 0g basalt (control) had higher mean in root dry weight compared to plants that were treated with basalt application. Finally, there was no significant difference in total dry weight between Treatment 5 (240 g basalt), Treatment 1 (0 g basalt), Treatment 3 (80 g basalt) and Treatment 2 (40 g basalt) at $p < 0.05$. However, Treatment 4 (160 g basalt) was significantly lower than the other plants. Treatment 5 was found to be higher by 33%, 24%, 22% and 1% compared to Treatment 4, Treatment 2, Treatment 3 and Treatment 1, respectively. Application of high dosage of ground basalt increased biomass production of the plant. These results were in accordance to other similar studies on different crops, such as cocoa (Anda et al. 2013), maize (Shamshuddin and Fauziah 2010b) and rice (Shazana et al. 2013, Shamshuddin et al. 2016, Panhwar et al. 2016).

Table 1. Biomass production after six months application of basalt.

	Dry weight (g)			
Basalt rate (g/plant)	Leaf	Stem	Root	Total
0	119.74a ±12.60	78.50a ±5.96	73.47a ±11.43	271.71a ±22.61
40	98.06a ±8.87	61.26a ±10.75	60.74ab ±2.06	220.06ab ±20.58
80	97.44a ±3.90	85.37a ±2.76	40.66b ±4.87	223.47ab ±10.53
160	103.39a ±13.27	62.57a ±6.75	40.02b ±7.75	205.98b ±20.51
240	117.20a ±11.29	85.33a ±13.65	70.64a ±32.28	273.17a ±23.26
$LSD_{0.05}$	27.25	27.85	27.91	63.14

*means with same letter within same column are not significantly different at $p \leq 0.05$ (n=3)

Leaf Nutrients Content

Nutrient content of *Hevea* was significantly affected by basalt application after six months (Table 2). Treatment 2 and Treatment 5 plants were higher in phosphorus content compared to plants without basalt, classified as high according to nutrient sufficiency level. For Potassium, Treatment 3 and Treatment 4 showed high level of sufficiency. Although the value of nutrient content was high, there was no obvious toxicity symptoms such as scorching of the leaves observed. Recent study by Shafar et al. (2012) showed that new clones require more nutrients as their growth is more vigour compared to the previous clones such as RRIM 900. Plants also show nutrient deficiency symptoms visually even when analysed nutrient content indicate the reverse (Shafar et al. 2012, 2013). The application of basalt at the rate of 240g per plant increased all nutrient contents in the plants. These results can be related with the soil nutrient content as shown in Table 2, where all the micronutrients (P, K, Ca and Mg) increased when the soils were applied with basalt. Similar results were obtained when basalt was applied to the soil and nutrition of cocoa and rice increased significantly (Shamshuddin and Fauziah 2010a, 2010b, Shamshuddin et al. 2016). Increasing rate of basalt applied will increase the soils nutrient content availability and nutrient uptake, subsequently improved plant nutrition.

Table 2. Nutrient content in leaves tissue after six months of basalt application.

	Nutrient content (%)									
Basalt rate (g/plant)	N	SL	P	SL	K	SL	Ca	SL	Mg	SL
0	2.32ab ±0.17	L	0.16b ±0.01	L	0.87ab ±0.07	L	0.47a ±8.51	L	0.10a ±0.01	L
40	2.63a ±0.16	L	0.19ab ±0.01	H	0.61b ±0.27	L	0.42ab ±0.01	L	0.09a ±0.01	L
80	2.16b ±0.13	L	0.17ab ±0.01	L	1.30a ±0.05	H	0.36b ±0.03	L	0.10a ±0.01	L
160	2.23b ±0.07	L	0.16ab ±0.01	L	1.10a ±0.11	H	0.37b ±0.01	L	0.09a ±0.01	L
240	2.69a ±0.07	L	0.20a ±0.02	H	0.9ab ±0.06	L	0.39b ±0.03	L	0.10a ±0.01	L
$LSD_{0.05}$	0.40		0.04		0.43		0.07		0.03	

*means with same letter within same column are not significantly different at $p \leq 0.05$ (n=3)
**Critical value (after Noordin, 2013): N= 3.2 %, P= 0.19%, K= 1%, Ca= 0.6%, Mg= 0.23%
SL= sufficiency level, L= low, H= high

Initial Soil Chemical properties

Some chemical properties of the soil used were analysed before the experiment commenced to evaluate the fertility status. The result showed that the Rengam Series soil was acidic with pH value of 4.13. This soil also has very low cation exchange capacity (CEC) of 5.35 $cmol_c\ kg^{-1}$ which indicated that this soil could not retain much cation and too much nutrients applied from fertilizer will be leached into the groundwater (Shafar et al. 2013). Its low value of available phosphorus at 10.16 mg kg^{-1} indicated that this soil has problem of phosphate fixation by sesquioxides. Exchangeable cations (K, Ca, Mg, Al) were also very low (0.11, 0.24, 0.31, 1.69 $cmol_c\ kg^{-1}$, respectively) which will result in insufficient of nutrients and slower growth of plant if not fertilized enough. Aluminium content wass high and this will inhibit growth of some plant with lower tolerance of Al and acidity (Shamshuddin and Fauziah 2010a).

Final Soil Chemical Properties

Soil pH

Results from this study showed that Treatment 3 (80 g basalt) was higher than Treatment 1, Treatment 2, Treatment 4 and Treatment 5 by 29%, 28%, 24% and 14%, respectively six months after transplanting. However, all the treatments with basalt application had higher pH values than control plant (Figure 6). Dissolution of minerals in basalt will release nutrients in the soil solution. There are two important minerals in basalt, namely olivine and pyroxene. These two minerals will dissolve in the soil solution under the humid tropics conditions. Dissolution of olivine occurred slowly as follows:

$$Mg_2SiO_4 \rightarrow 2Mg^{2+} + SiO_4^{4-}$$

The SiO_4^{4-} then hydrolyzes immediately to produce large amount of hydroxyl which can be depicted as follows:

$$SiO_4^{4-} + 4H_2O \rightarrow Si(OH)_4 + 4OH^-$$

Overall reaction of olivine dissolution in the moist soil can be represented as follows (Shamshuddin and Fauziah 2010a):

$$4Mg^{2+} + 4SiO_4^{4-} + 4H_2O \rightarrow 4Mg^{2+} + Si(OH)_4 + 4OH^-$$

Pyroxene can also be hydrolysed in the moist soil with less amount of hydroxyl released into soil solution (Shamshuddin and Kapok 2010). The silicate anion (SiO_4^{4-}) from minerals is a very strong base. This silicate anions will react with protons from soil solution to form monosilicic acid (H_4SiO_4), weak acid (McBride 1994). These protons are provided by the ionization of water and produces OH^- resulting in the pH values increasing. Previous studies also shows the similar results, where with the application of basalt had increased the soil pH (Shazana et al. 2013, Anda et al. 2015).

According to MSU (2011), soil pH influences the ability of nutrient to dissolve in water. This solubility cause plant root to only absorb nutrients that dissolve in solution. At low pH (5.0 to 6.0), micronutrients such as iron, manganese, zinc and boron are highly soluble and are available for plant uptake. However, if pH is too low (below 5.0), the concentration of micronutrients in the soil solution will become higher to a certain extent, reaching toxic level for plant growth.

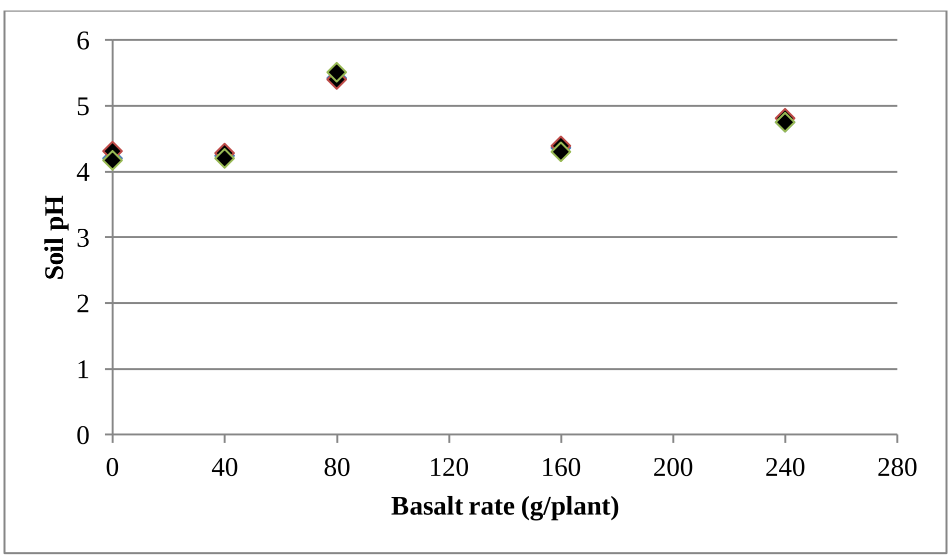

Figure 6. Soil pH between treatments in Rengam Soil Series after six months of ground basalt application (*n*= 3).

Soil Nutrient Content

All nutrients (P, K, Ca and Mg) in the soil, increased with the increasing rate of applied basalt which continued to release nutrients in the soil system even after six months of application (Table 4). Available P is increased tremendously in soils applied with basalt (213%, 209%, 161%, 91% and 78% for Treatment 4, Treatment 3, Treatment 5, Treatment 2 and Treatment 1, respectively) compared to before the experiment was carried out. Similar trends were observed for exchangeable cation (K, Ca and Mg) contents in the soil. With increasing soil pH, exchangeable Al concentration was decreased. The highest rate of basalt at 240 g per plant reduced Al concentration up 74% after six months of application. Basalt disintegration releases nutrients in the soil solution by a relatively slow process. High rate of application over time may ensure nutrient release for a long period. Dissolution of apatite mineral in basalt increases available P in the soil. However, in the highly weathered soil system, most of released P will be fixed by oxides. Previous study showed that P released from basalt was less available in the Munchong series (Oxisol) than Bungor series (Ultisol) (Shamshuddin and Kapok 2010). Basalt acts as a good soil amendment for certain period of time (Gillman et al. 2001, Shamshuddin and Fauziah 2010b). Boniao et al. (2002) reported that basalt was completely dissolved after nine months. Anda (2006) reported that the effect of basalt application on the soil can last for more than two years. Ground basalt is a good alternative to limestone as a soil ameliorant (Gillman et al. 2001, Gillman et al. 2002, Anda et al. 2015, Shamshuddin et al. 2016). Basalt contains K and P in adequate amounts. Thus, by using basalt as a soil ameliorant, P and K fertilizer applications can be reduced (Shamshuddin and Kapok 2010).

Table 4. Nutrient content in soil after 6 months of basalt application.

Treatment	Rate of basalt	Available P	Exchangeable cations			
			K	Ca	Mg	Al
	(g/tree)	(mg kg^{-1})	($cmol_c$ kg^{-1})			
T1	0	18.10c ±0.17	3.09a ±0.01	1.34e ±0.01	0.37d ±0.01	1.63a ±0.03
T2	40	19.39c ±0.06	1.57b ±0.01	2.16b ±0.01	0.50b ±0.01	1.48b ±0.01
T3	80	31.43a ±0.58	0.92d ±0.01	1.87c ±0.01	0.54a ±0.01	1.36c ±0.01
T4	160	31.85a ±0.12	1.42c ±0.01	1.57d ±0.01	0.32e ±0.01	1.18d ±0.01
T5	240	26.53b ±1.15	0.62e ±0.01	3.00a ±0.01	0.48c ±0.01	0.97e ±0.03
$LSD_{0.05}$		1.84	0.02	0.02	0.02	0.07

*means with same letter within same column are not significantly different at $p \leq 0.05$ (*n*=3)

CONCLUSION

Generally, basalt improves the soil chemical properties (pH and nutrient) in Rengam soil series. However, because basalt is dissolved slowly in the soil system, thus in earlier months basalt could fix the available nutrient in the soil and the soil structure first. Basalt has a huge potential in the future to become a cheaper source of long term soil amelioration for the rubber industry. From the results of plant growth in terms of height, girth, biomass production and favourable increase in plant nutrition and soil chemical properties (increase in pH, available P, K, Ca, Mg and decrease in Al concentration), it is suggested that 240 g per plant of basalt could be used as soil amelioration.

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