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Influence of fertilizer rates and soil series on growth performance of natural rubber (*Hevea brasiliensis)* latex timber clones

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Abstract

The increasing demand for natural rubber is due to its preference over synthetic rubber, especially in the automobile industries. Adequate nutrition for immature rubber is considerably necessary to boost its vegetative growth and yield in later stage. This study was conducted in the nursery with complete randomized design (CRD) in factorial over a period of 24 weeks. The plants used were RRIM 2001, RRIM 2025 and RRIM 3001 in two different soil series Holyrood (Oxisols) and Munchong (Ultisols) with five fertilizer treatments as 0% (F1), 50% (F2), 100% (F3), 150% (F4), 200% (F5). The fertilizer rates (which were represented in percentage) are F2 (78g m^{-2}), F3 (156g m^{-2}), F4 (234gm^{-2}), F5 (312gm^{-2}), respectively. Information on plant height and girth were recorded together with foliar analysis on different treatments. There was a significant differences among the treatments ($p<0.05$). Poor performances were recorded in control, 50% and 100% fertilizer rates which caused retarded growth and undesirable symptoms in the plants. However, optimum fertilizer level was achieved at 150% (234g m^{-2}) as growth and development was significantly increased at the medium level. However, 200% appeared in excessive for the plants and showed a detrimental effect. Generally, Munchong soil series and RRIM 3001 showed better performance compared to Holyrood soil series and other clones. Therefore, increase in growth and development will be achieved if this optimum fertilizer level is adopted by rubber growers in the estate especially at the immature stage of rubber.

Keywords: *Hevea brasiliensis,* soil series, immature rubber, latex timber clones.
Abbreviations: RRIM_Rubber Research Institute of Malaysia; RISDA_Rubber Industry Smallholders Development Authority; IRSG_International Rubber Study Group.

Introduction

Natural rubber *Hevea brasiliensis* is a tropical crop that requires about 180–250 cm of rainfall per year and a temperature of 25–35 ^{o}C. It can be grown on a deep firm soil of the loamy texture with free drainage and tolerates a water table of 100 cm from the surface and below with life span of approximately thirty years and reach a height of 18-20m (Malaysia Rubber Board, 2009). The latex can be used for the production of more than 40,000 products including medical devices. It has been categorized as a strategic raw material (Mooibroek and Cornish, 2000). The importance of rubber as one of the polymers naturally produced by plants cannot be over emphasized especially among the developing countries. However, International Rubber Study Group (IRSG) noted that the demand for natural rubber will continue till the end of decade due to increasing demand for tyres and other products in automobile industries. Evans (2011) reported that in 2010 the consumption of natural rubber was 10.7 million tonnes for all markets (tyre and non-tyre) which is predicted to increase to 15.4 million tonnes by 2020. In the same vein, it was observed that natural rubber will continue to play major roles in rubber industry. However, increasing demand in latex has been attributed to the continuous depletion in reserve fossil fuel and significant preference by consumer for natural rubber over synthetic rubber. Furthermore, the rise in production due to anticipated demand in new planting would depend on the achievement of rubber community in addressing the looming threats to rubber cultivation such as long gestation and low yield (Nugawela and Asoka, 2011).
Therefore, to ameliorate the current shortage of natural rubber and higher anticipated future demand as speculated by the IRSG, production needs to be increased through optimum fertilizer application and improved agronomical practices especially at the early growth stage. On the other hand, Malaysia Rubber Board (2009) observed that farmers achieve good economic impact and minimizes nutrients loss to the environment through adequate fertilizer application to the rubber. Meanwhile, efficient fertilizer application to rubber at immature phase requires regular assessment of plant nutrient status through plant nutrient analysis.

The frequent plant tissue analysis forms part of the basis for future nutrients management decisions and correct measure. It may include soil improvement, foliar nutrition or possibly change to an alternative crop (Mikkelsen, 2009). Noordin et al. (1988) noted that optimum yield could be achieved in young rubber trees with the application of N, P, K and Mg as major nutrients until tapping. Meanwhile, excessive nitrogen application should be prevented because it increases vegetative growth and tree height which may lead to trunk breakage. Furthermore, Evans (2011) observed that poor nutrient utilization and toxicities may cause unusual visual symptoms and result into decrease in productivity of plants. However, understanding the function and mobility of each of the essential nutrients would help in discovering which of the

Table 1. Plant nutrients, their function and forms were used in this study.

Nutrients	Functions	Form
Nitrogen	Needed for protein formation	NO_3^-, NH_4^+
Phosphorus	Seed formation and early maturity	$H_2PO_4^-$, HPO_4^{2-}
Potassium	Carbohydrate metabolism	K^+
Magnesium	Chlorophyll formation (photosynthesis)	Mg^{2+}

Source: (Shamshuddin and Ishak, 2010).

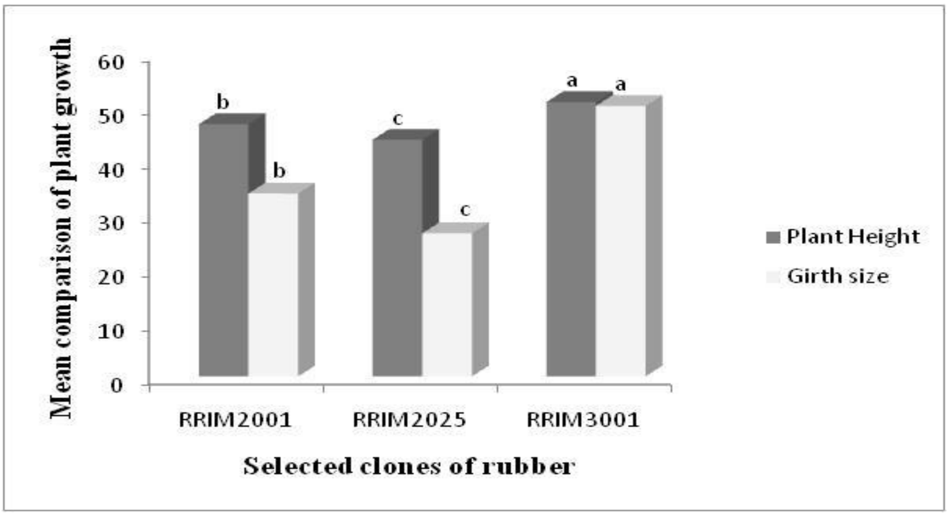

Fig 1. Effect of Munchong soil series on plant physiological traits of three immature rubber clones.

Table 2. Physical and chemical properties and characterization of the soils used.

Soils series	pH	CEC	Particle sizes			Total Available			Exch	
			Clay	Silt	Sand	C	N	P	K	Mg
		$(Cmol_c (+)/kg{-1})$	(%)	(%)	(%)	(%)	ppm	Cmol/kg		
Munchong	4.20	8.0	62.7	10.89	26.21	1.6	0.13	250	0.9	0.6
Holyrood	4.40	4.7	22.39	9.93	67.57	0.4	0.09	300	0.7	0.9

Munchong: Oxisols, Holyrood: Ultisols.

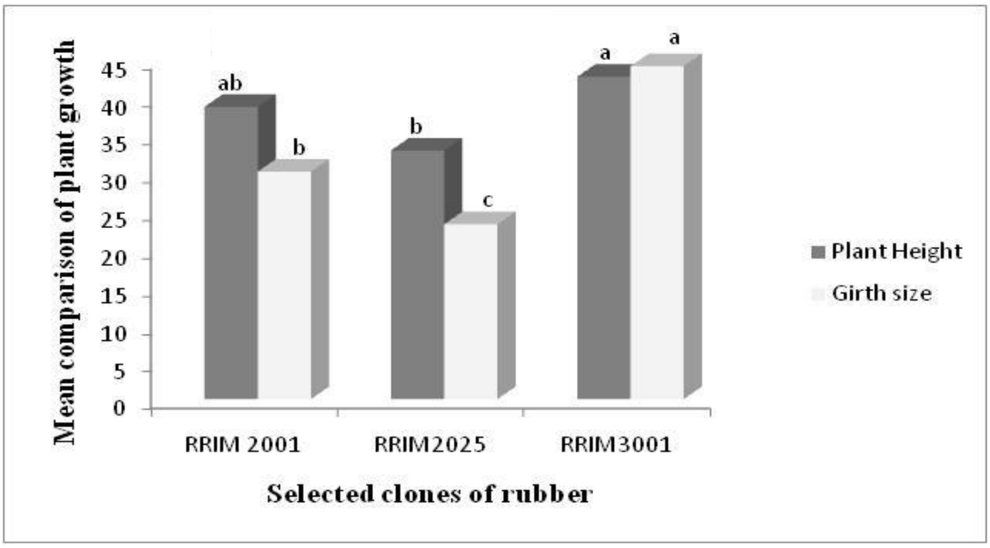

Fig 2. Effect of Holyrood soil series plant physiological traits of three immature rubber clones.

nutrient is responsible for a deficiency or toxicity symptom. Plant analysis consists of testing nutrient concentrations in any of the plant parts during specific growth stages (Jacobsen and Jasper, 1991).

However, the physical properties and chemical compositions of a soil play important roles in determining the nutritional status of natural rubber, especially during the immature phase. Also knowledge on soils helps in proper fertilizer application management, as different classes of soils respond differently to the fertilizers (Malaysia Rubber Board, 2009).

Pushparajah, (1994) observed a relationship between plant tissue testing and productivity. Assessment of fertilizer requirement can be done based on such an analysis. This is because, there may be a situation where soil contains an adequate amount of nutrient for plant uptake but may be inhibited by lack of another element, e.g. where N is not available it reduces K to uptake. In this case, leaf analysis will reveal the need for N and K fertilizers.

This study aims at solving the problem associated with under- or over-fertilization through plant tissue analysis of different rubber clones grown in different soil types and fertilizer rates. It will also enables rubber growers to determine the optimum dosage needed for each rubber clone coupled with in-depth knowledge of growth pattern.

Results and Discussion

Properties characterization of the soils

The comparative analysis of physical and chemical composition of the two soil series used in this study is shown in Table 2. Holyrood series can be grouped into sub-recent alluvium and recent alluvium parent material. The soil is yellowish brown in color with weak and fine sub-angular blocky structure. The consistency is very friable to loose because is very sandy. Taxonomically, it was classified as fine loamy, kaolinitic, isohyperthermic, Typic Quartzip-samment (Noordin et al., 1988). The prevalent particle size distribution for Holyrood series is sand (67.57%); thereafter, clay and silt. The value, which is 4.7 $cmol^+ kg^{-1}$, shows that the cation exchange capacity C.E.C in the soil is low. This shows the limitation of the soil to retain cations. The pH value of 4.40 indicates the acidic nature of the soil. Munchong soil series were derived from sedimentary rock. The color of shale was yellow, strongly brown and highly weathered. The prevalent particle size distribution is clay (62.79%); thereafter, sand and silt. The presence of silt in this soil may indicate a degree of weathering which has taken place (Anda et al., 2008).

The silt content in the soil is a reliable indicator of the remaining weatherable minerals of soils as these minerals will become part of the clay fraction when they weathered. Also the value which is 8.1 $cmol^+ kg^{-1}$ indicates that the cation exchange capacity in the soil is low. However, these show the limitation of the soil to retain cations. However, the pH value of 4.20 shows that the soil is acidic. Ultisols and Oxisols in the tropics require essential plant nutrients and good soil structure as a result of lack of organic matter which can make them supplied them for plant growth (Shamshuddin and Daud, 2010).

Foliar analysis and yield performance

Indications from statistical analysis of foliar result showed that, plant on Muchong soil series (Oxisols) performed better and significantly different ($p<0.05$) when compared to Holyrood soil series in terms of nutrient elements and plants growth. Though, Munchong has been rated as number one soil series for rubber cultivation in Malaysia (Malaysia Rubber Board). In nutrients utilization of the plants, nitrogen appeared to be high, especially at 200% (F5), results in the yellowish of the leaves, while P and Mg were not significantly different and insufficient for the plants in both soils. Meanwhile, too much of P content may cause deficiency of some other micro-nutrients in the soil such as Zn, which may adversely affect plant growth.

Moreover, N is a key to soil fertility and its adequate amount is required for plant growth (Dreyfus et al., 1987). In this study, high N and its detrimental effect on the treatments is similar to the result of Mokhatar and Noordin (2011), which states that, excessive application of fertilizer with higher amount of N may cause scorching of leaves and roots damage. On the other hand, Evans (2011) suggested that, N involves in vegetative growth but its excess should be avoided as may cause weak stems and frequent lodging of the plant.

Verheye (2010) observed that deficiencies of K and Mg can be recorded on Holyrood soil series. However, Rubber is planted on acid soils in Malaysia, which may require at least 25% of P because it gives an advantage in the initial growth stages of rubber (Pushparajah et al.,1990). This is essential because it enhances plant ability to tolerate drought and reduce susceptibility to pests and diseases attack. The need for K in plant growth is not as important when compared to N and P (Jessy, 2011). Fertilizer is essential for rubber in the vegetative developmental stage (first 6 years) when biomass is being built up. In vegetative developmental stage, nursery and young rubbers abundantly receive a generous NPK fertilization, which aids their fast growth at the early stage.

Meanwhile, too much of Mg and Ca should be avoided because it may cause instability in the latex vessel (Verheye, 2010). In addition, treatments with 50% and 100% fertilizer rates exhibit undesirable visual symptoms and low yield, which may be as a result of insufficient nutrients and hidden hunger, while the controls (treatments without fertilizer) are poorly performed with no significant differences in nutrients categories in both soils.

Amongst the clones, RRIM 3001 performed best under these nutrients composition (in the fertilizer rates) followed by RRIM 2001, which may be as result of its special traits as a new clone (based on the findings of Malaysia Rubber Board, 2009). This clone has a latex production potential of more than 3000 kg/ha/year and is suitable for planting especially in large scale and could help to generate more income. This clone is still under evaluation in different environmental conditions and soil types. The RRIM 2025 clone showed the least performance in both soils.

On the other hands, the best plant growth was generally achieved at 150% (234g m^{-2}) of fertilizer and was significantly different among nutrients categories.

Table 3. Comparison of nutrients categories on Munchong soil series and fertilizer rates.

Treatment	Nitrogen g kg $^{-1}$	Phosphorus g kg $^{-1}$	Potassium g kg $^{-1}$	Magnesium g kg $^{-1}$
F10% Control	1.43c	0.15d	0.79d	0.16d
F2 (78g m $^{-2}$)	2.39b	0.18c	1.13c	0.18c
F3 (156g m $^{-2}$)	2.76b	0.18c	1.18c	0.19c
F4 (234gm $^{-2}$)	3.34a	0.24b	1.36b	0.24b
F5 (312gm $^{-2}$)	3.59a	0.26a	1.64a	0.27a

Means within column with the same letter are not significantly different at $p<0.05$.

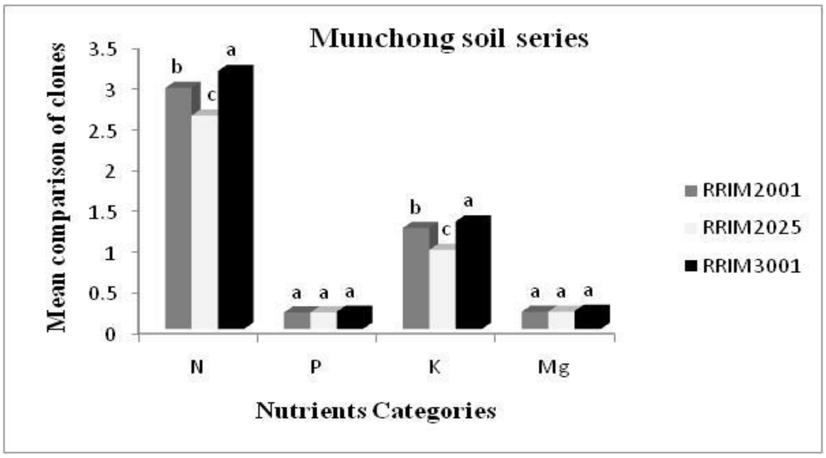

Fig 3. Response of different clones of immature rubber to fertilizer rates in Munchong soil series.

Table 4. Comparison of nutrients categories on Holyrood soil series and fertilizer rates.

Treatment	Nitrogen g kg $^{-1}$	Phosphorus g kg $^{-1}$	Potassium g kg $^{-1}$	Magnesium g kg $^{-1}$
F1 0% Control	1.69e	0.17c	0.83e	0.16c
F2 (78g m $^{-2}$)	2.91d	0.16c	1.13c	0.19b
F3 (156g m $^{-2}$)	2.97c	0.19b	0.87d	0.20b
F4 (234gm $^{-2}$)	3.42b	0.25a	1.44b	0.25a
F5 (312gm $^{-2}$)	3.62a	0.26a	1.62a	0.27a

Means within column with the same letter are not significantly different at $p<0.05$.

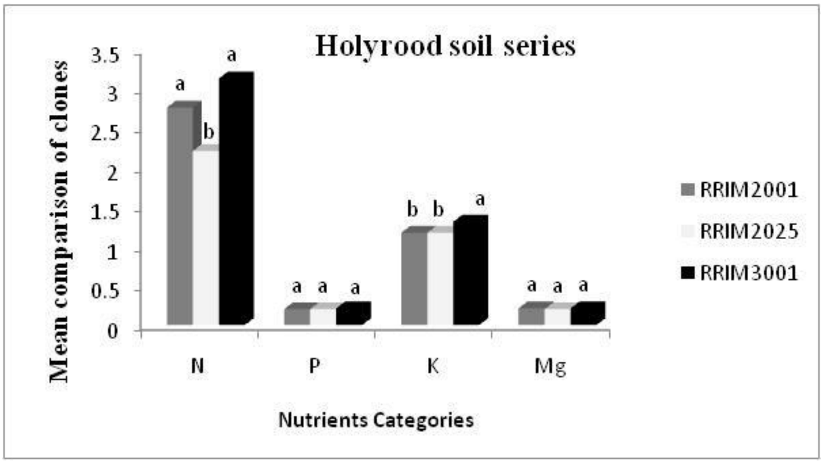

Fig 4. Response of different clones of immature rubber to fertilizer rates in Holyrood soil series.

Table 5. Effect of fertilizer rates on the plant physiological triats in Munchong soil seris **.**

Treatment	Plant Height (cm^2)	Girth Size (mm)
F1 0% Control	30.4^d	14.9^e
F2 (78g m^{-2})	43.3^c	25.4^d
F3 (156g m^{-2})	54.5^b	40.2^c
F4 (234gm^{-2})	66.5^a	59.3^a
F5 (312gm^{-2})	41.8^c	45.1^b

Means within column with the same letter are not significantly different at $p<0.05$.

Table 6. Effect of fertilizer rates on the plant physiological traits in Holyrood soil series.

Treatments	Plant Height (cm^2)	Girth Size (mm)
F1 0% Control	26.0^c	13.0^e
F2 (78g m^{-2})	38.1^b	21.9^d
F3 (156g m^{-2})	40.0^a	33.0^c
F4 (234gm^{-2})	50.8^a	53.6^a
F5 (312gm^{-2})	30.1^c	41.1^b

Table 7. Mean square of plant pyhsiological traits on Munchong soil series.

Source	df	Plant Height	Giirth size
Fertilizer	4	1126.3*	1798.5*
Clones	2	121.4*	1474.3*
Fertilizer× clone	8	40.3*	52.10*
Error	15	8.05	47.07

Meanwhile, 200% (312g m^{-2}) of fertilizer appeared to be excessive for the plants because it declined the plants growth (Table 3 and 4). The study showed that 150% of fertilizer could be adopted as optimum level of fertilizer rate for the plants yield and an attempt to add more can cause toxicity, environmental degradation and waste of resources.

Growth parameters

The fertilizer rates increased plants growth both in height and girth size (Table 5 and 6). Naturally, the rubber girth size is very important because it determines the yield of the plant in terms of latex flow and its quality. The growth was generally increased and significantly different in both soils. Plants performed better in Munchong soil series compared to Holyrood soils. This may be attributed to the ability of the former to retain water and nutrients due to high clay content in the soil. Moreover, the later contains higher amount of sand, lacking ability to retain rain water and nutrients because it drains easily. Meanwhile, (Slavich et al., 2010) observed that sandy soil poses many constraints to agriculture due to its poor nutrients holding capacity as a result of low organic matter content and cation exchange capacity (CEC). The plant growth increased under incremental rate of fertilizers. The control treatment (without fertilizer) poorly performed, followed by 50%, 100%. The 150% fertilizer rate was observed as optimum level. The declined in the growth was recorded after application of 200% fertilizer, which appeared to be excessive. In addition, the plant girth size tremendously increased at all treatments. However, regular application of N, P and K fertilizers may add the fertility of the soil and appreciable increment in girth size when N and K are added (Singh, 2010). Furthermore, there was a significant difference among the clones, in terms of height and girth size (Fig 1 and 2). According to Duncan's grouping, RRIM 3001 clone performed better and significantly higher ($p<0.05$), followed by RRIM 2001. The RRIM 2025 clone showed a low performance in both soils at all fertilizer rates. In addition, control plants with no fertilizer performed poorly and showed the lowest values (Table 5 and 6). Though, slow growth and unusual visual symptoms with decrease in productivity of crop may be as a result of nutrient deficiency (Evans, 2011).

The RRIM 3001 clone recorded better growth and was found to suffer the bark burst when planted in lateritic soil. On the other hand, RRIM 2025 which had the least performance had also shown a promising characteristic in early trials base on the available track record of five years yield data and other secondary characteristics from trials in limited scale such as small scale clone trial (SSCT) (Malaysia Rubber Board, 2009).

Materials and methods

Experimental design and treatments

Study was carried in research farm of the Universiti Putra Malaysia, under shelter house. Three different clones (RRIM 2001, RRIM 2025 and RRIM 3001) were examined in Holyrood and Munchong soil series using five fertilizer levels as treatments. There were five treatments with three replicates, containing four plants for each treatment using factorial in complete randomized design (CRD). The fertilizer used in this study was RISDA 1 with formulation ratio of 10.7% N: 16.6% P205: 9.5%K20: 2.4%MgO. RISDA is abbreviation of Rubber Industry Smallholder Development Authority which is a company responsible for the supply of fertilizer to the smallholders in Malaysia. Therefore, RISDA 1 was used as standard for the treatments. In order to get fertilizer rate, the standard rate will be less than 50% of each ratio on the nutrients component. The same methods applied to 100%, 150% and 200%, respectively. The unfertilized scion was used as control in the study. The respective treatments had the equivalent of control with no fertilizer (F1), 50% (F2), 100% (F3), 150% (F4), 200% (F5). The quantity which represents each of the percentage were F2 (78g m^{-2}), F3 (156g m^{-2}), F4 (234g m^{-2}), F5 (312g m^{-2}), respectively. The plants used were RRIM 2001, RRIM 2025 and RRIM 3301 clone series at six-month-old in 15 x 33cm (15kg/bag) polythene bags filled with Holyrood and Munchong soil series. Fertilizer application was carried out at four weeks interval with different rates. The study duration was 24 weeks, and data were recorded at the end of the study. Plant height was measured from the soil surface to the shoot tip using standard measuring tape.

Table 8. Mean square of plant pyhsiological traits on Holyrood soil series.

Source of variation	df	Plant Height	Giirth size
Fertilizer	4	651.1*	1511.2*
Clones	2	244.0*	1141.9*
Fertilizer× clone	8	31.5*	22.2*
Error	15	37.9	2.8

NB: *Significant different at $p<0.05$

Table 9. Mean square of nutrients categories on Munchong soil series.

Source of variation	df	N	P	K	Mg
Fertilizer	4	3.4*	0.01*	0.72*	0.01*
Clone	2	0.8*	0.0003ns	0.33*	0.0004ns
Fertilizer×clone	8	0.2*	0.0002ns	0.13*	0.0008ns
Error	15	0.0003	0.0003	0.0003	0.0003

Table 10. Mean square of nutrients categories on Holyrood soil series.

Source of variation	df	N	P	K	Mg
Fertilizer	4	4.3*	0.01*	0.6*	0.01*
Clone	2	2.1*	0.0001ns	0.06*	0.0001ns
Fertilizer×clone	8	0.4*	0.0003ns	0.01*	0.0001ns
Error	15	0.0003	0.0001	0.0003	0.0002

The plant girth size was measured at 10cm from the soil using digital Venier Caliper (Mitutoyo Inc. Japan).

Leaf Sampling and nutrients analysis

The leaves were sampled from 30 trees across the treatments, according to Malaysia Rubber Board foliar sample techniques with four basal leaves from the first sub-terminal whorl. Also before drying and sample preparation, the foliar samples were pooled and sub-sampled in the laboratory. The leaves were oven dried at 70^{o}C for 48 hours and; thereafter, grinded. A 0.25 g of the weighed grinded dried samples was put into digestion tube.

Also 5 ml of concentrated sulphuric acid (H_2SO_4) was added, shaked and left for about 2 hours to moist. Then samples were placed in the digestion block at the temperature of 450^{o}C in the fume chamber for approximately 45minutes. The digestion tubes were removed and allowed to cool, after which, 2 ml of hydrogen peroxide (H_2O_2) was added and the heating process was repeated in the fume chamber.

After the stipulated heating period, the sample in the tube becomes colourless. Then the solution was left to cool and later diluted with distilled water to make up 100 ml. Thereafter, it was analyzed for N, P and K using Auto Analyzer, while Mg was analyzed with Atomic Absorption Spectrophotometer. Table 1. shows the plant nutrient, functions and forms, in which they were absorbed by the plants.

Statistical analysis

Data analysis was carried out through analysis of variance (ANOVA) using Statistical Analysis System (SAS 9.1) version. Duncan's multiple range tests at $p<0.05$ was employed for mean comparison. Bar charts were drawn to show the effect of fertilizer rates on growth performance of the clones in terms of girth and height in soil series.

Conclusion

This study showed that the soil requires essential nutrients for adequate plant growth and survival. Excessive fertilizer application could also cause toxicity and hazard to the plant and can impose extra costs to rubber growers. Similarly, increase in yield and growth can be achieved where fertilizer rate at optimum level adopted at immature stage of natural rubber. From all indications, it was shown that 150% (234g m^{-2}) should be used as optimum fertilizer level. This was due to its significant increase in growth and vegetative performance. However, insufficient dosage 50% (78g m^{-2}) and 100% (156g m^{-2}) should be avoided, as they may cause hidden hunger, unusual visual symptoms and retarded growth. On the other hand, high dosage 200% (312g m^{-2}) should be prevented as this may result into toxicity in plant and decline in growth. In general, RRIM 3001 and Munchong soil series performed better compared to other clones and soil series, respectively. The study suggests that fertilizer levels by RISDA 1 should be adjusted based on the findings, in order to achieve appreciable growth of natural rubber especially at the immature stage.

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References

Anda M, Shamshudin J, Fauziah C, Omar S (2008) Mineralogy and factors controlling charge development of three Oxisols developed from different parent materials. Geoderma. 143 (1-2):153-167

Dreyfus B, Diem HG, Freire J, Keya S, Dommergues Y (1987) Nitrogen fixation in tropical agriculture and forestry. Microbial technology in the developping world. Oxford University Press, Oxford, pp. 7- 50

Daud NW, Mokhatar SJ, Ishak CF (2012) Assessment of selected Hevea brasiliensis (RRIM 2000 Series) seeds for rootstocks production. Afr J of Agric Res, 7(21), 3209-3216

Evans S (2011) International Rubber Study Group predicts decade of strong tyre demand. Tyrepress Magazine, (9), 1. www.tyrepress.com. Accessed: November 19, 2012

Jacobsen JS, Jasper CD (1991) Diagnosis of Nutrient Deficiencies in Alfalfa and Wheat: Montana State University, Extension Service

Jessy M, (2011) Potassium management in plantation crops with special reference to tea, coffee and rubber. Karnataka J Agric Sci. 24(1):67-74

Malaysia Rubber Board, (2009) Fertilizer application and field maintenance In: MRB (eds), Rubber plantation and processing technologies. Malaysia Rubber Board Kuala Press,Kuala Lumpur, pp. 23-25

Mikkelsen R (2009) Tissue testing can save your crops.In: International Plant Nutrition Institute (eds) Plant nutrition today. IPNI Publishing. Accessed: November 22, 2012.

Mokhatar SJ, Daud NW (2011) Performance of *Hevea brasiliensis* on Haplic Acrisol Soil as Affected by Different Source of Fertilizer. Intl J of Appl Sci and Tech. 1: 50-53

Mooibroek H, Cornish K (2000) Alternative sources of natural rubber. Appl Microbiol Biotechnol. 53: 355-365

Noordin W, Zainol M, Lau C (1988) Nuutrients categories in immature rubber. In: Rubber Research Institute of Malaysia (eds) Management of soils and nutrition of *Hevea*. RRIM Press, Kuala Lumpur, pp. 7- 8

Nugawela A, Jom J (2011) Future of natural rubber: High prices, tough challanges. Rubber Asia Magazine .www.rubberasia.com. Accessed: October 25 , 2012

Pushparajah E (1994) Leaf analysis and soil testing for plantation tree crops: Asian Studies on the Pacific Coast (ASPAC) and Fertilizer and food technology centre (FFTC), Extension Bulletin. pp. 35 - 42

Pushparajah E, Cnah, Magat S (1990) Phosphorus requirements and management of oil palm, coconut and rubber. Phosphorus requirements for sustainable agriculture in Asia and Oceania, 399-425.

Rubber Research Institute of Malaysia (1990) The range of leaf values for assessing leaf nutrient status. In: RRIM (eds), Manual for diagnosing nutritional requirements for *Hevea*. Vinlin Sdn Bhd, Kuala Lumpur, pp. 10-13

Shamshuddin J, Daud NW (2011) Classification and Management of Highly Weathered Soils in Malaysia for Production of Plantation Crops. Intech open Sci. 4:75 - 86

Shamshuddin J, Ishak CF (2010) fertilizer requirement and management. Weathered tropical soils the ultisols and oxisols. Universiti Putra Malaysia Press, pp 9: 134

Singh RP, Mandal D, Mercykutty J, Sharma AC (2010) Response of rubber (*Hevea brasiliensis*) to NPK fertilizers in the Lower Brahmaputra Valley Zone of Assam. Natural Rubber Research 23:28-36

Slavich AP, Tam BHM, Thinh BNT (2010) Managing water and nutrients in sandy soils for tree crop production in Central Coastal Vietnam.In: 19th World Congress of Soil Science: Soil solutions for a changing world, Brisbane, Australia, 1st - 6th August, 2010

Verheye W (2010) Growth and production of rubber. In: Verheye, W (ed) Land use, land cover and soil sciences.Encyclopedia of life support systems (EOLSS), UNESCO – EOLSS Oxford, United Kindom http:www.eolss.net. Accessed: October 13, 2012