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Nutrient Assessment with Omission Pot Trials for Management of Rubber Growing Soil

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Abstract

Rubber-growing soils in southern Thailand are usually deficient in both macro- and micronutrients. Omission pot trial is an excellent tool for nutrient assessment because it can indicate the most limiting nutrient and the order of limitation. Maize is generally used as a test plant, but the difference in nutrient response of maize and rubber is not clearly understood. An omission pot trial with 10 treatments (All, -N, -P, -K, -Mg, -S, -Zn, -Cu, -B, and -Lime) was conducted. The soil samples were limed with $Ca(OH)_2$ to pH 6, except for that used for the -Lime treatment. Equivalent amounts of 400 kg ha^{-1} of N, 120 of P, 175 of K, 75 of Mg, 100 of S, 6 of Zn, 4 of Cu and 2 kg ha^{-1} of B, were added in the All treatment. Nutrient X was omitted in the -X treatment. Maize and rubber were grown as test plants. The plant growth indices were measured after 30 days for maize and after 9 months for rubber. The limiting nutrients of both plants were N, P, and Ca (lime). Rubber growth in the field, which received government-recommended and omission-based fertilization, were not different.

Keywords: nutrient assessment, omission trial, rubber growing soil, nutrient management

1. Introduction

Thailand is a leader in natural rubber production and has a planted area of 2.87 million hectares and a productive area of 1.93 million hectares, which yielded 3.25 million metric tons of rubber in 2010 (Rubber Research Institute of Thailand [RRIT], 2011). Most of the planted area is located in the south of the country, where soils are acidic and highly weathered. The soils are usually deficient in both macro- and micronutrients, such as N, P, K, Ca, Mg, S, and Cu (Nilnond et al., 1995). Watson (1989); Karthikakuttyamma et al. (2000) stated that N deficiency will lead to reduced rubber leaf size and tree girthing, and eventually to stunting of the tree. In P deficiency on young un-branched trees, the symptoms are first found in leaves in the middle whorl up to the upper whorl and a considerable defoliation may also occur (Karthikakuttyamma et al., 2000). K participates in glycolysis, respiration, laticiferous vessel formation, and osmotic rebalancing after tapping (Jacob et al., 1989). Sivanadyan et al. (1975) reported that lack of K limits the active leaf area and reduces the photosynthetic activity of the foliage, resulting in slow growth and a prolonged immature growth phase. Simultaneously, Pushparajah (1977) reported improvement in latex flow and its stability due to application of K that in addition to improving growth of trees and stimulates bark renewal. Ca is involved in cell division, growth, root lengthening and activation of enzymes. Yingjajaval and Bangjan (2006) found that large quantities of Ca are accumulated in RRIM 600 tree biomass and Ca is needed for growth of trees, especially those cultivated in acid soil. However, high amounts of Ca may accumulate in the bark, as Ca oxalate crystals, which have deleterious effect on latex formation and flow (Watson, 1989; Krishnakuma & Potty, 1992). Mg occupies the central position of chlorophyll and so, it is needed for photosynthesis and is an important cofactor for the production of ATP. Mg aids in the formation of sugar, proteins, oils and fats. It is a specific activator of several enzymes. In rubber, high levels of Mg in latex results in latex instability. On young un-branched trees, the symptoms first appear on the lower, older leaves and in mature rubber on leaves fully exposed to sunlight. In extreme deficiency, there can be defoliation and reduction in tree growth (Watson, 1989; Karthikakuttyamma et al., 2000). An 8-year-old to 15-year-old RRIM 600 rubber clone, which produces 2,500 kg of dry rubber ha^{-1} $year^{-1}$, required approximate 142 g $tree^{-1}$ $year^{-1}$ of N, 16 of P, 95 of K, 120 of Ca, and 28 g $tree^{-1}$ $year^{-1}$ of Mg (Yingjajaval & Banjan, 2006). Rubber is usually grown repeatedly on the same area for a long period, and according to the general recommendation of the Rubber Research Institute of Thailand, farmers usually apply

N-P-K compound fertilizers alone regardless of the soil nutrient status. Therefore, deficiencies or imbalances in secondary and micronutrients tend to occur (Kungpisadan, 2009).

Soil and plant analyses are commonly performed to assess the fertility status of a soil. However, the analytical results do not indicate the most limiting nutrient according to Liebig's law of the minimum "the minimum nutrient is the factor that governs and controls growth and potential yield of crop". An omission pot trial provides a visible order of crop response to nutrient availability. The trial has been successfully used for the nutrient assessment of neck orange- (*Citrus veticulata* Blanco.) and mangosteen- (*Garcinia mangstana* Linn.) growing soils (Lim et al., 1993; Nilnond et al., 1995). Maize (*Zea mays*) is commonly used as a test plant because of its well-characterized responses to nutrient deficiencies, rapid growth, and uniform development from the seed (Bell, 2002; O'Sullivan, 1997). Onthong and Osaki (2006) found that rubber roots can exude citric and oxalic acids, which enhance the P acquisition of the roots by increasing the solubility of P and detoxifying Al via complex formation. The roots of maize also detoxify Al through the exudation of organic acids (Ma et al., 2001). Similarity between the two species based on the roots excretions alone is very weak. An annual monocotyledon is too easily assimilated to a perennial dicotyledon. Thus, this study was conducted to assess the order of nutrient restriction using maize as the test plant and to compare the nutrient response of maize and rubber in both pot and field experiment.

2. Materials and Method

2.1 Materials

2.1.1 Omission Pot Trials

Seeds of sweet maize (*Zea mays* Linn.) and the uniform poly-bag budded stump at one-whorl stage of RRIM 600 rubber clone were used as test plants. The experiments were carried out in a completely randomized design with 10 treatments (All, -N, -P, -K, -Mg, -S, -Zn, -Cu, -B, and -Lime) and 4 replications. A representative rubber-growing soil was fine, kaolinitic, and isohyperthermic Typic Endoaquults (Soil Taxonomy classification).

2.1.2 Field Experiment

A two-year-old RRIM 600 plantation was selected to study the effect of 3 treatments of fertilizer using: without fertilizer, a Thai government-recommended fertilizer, and fertilizer based on the nutrients assessed by omission pot trials.

2.2 Methods

2.2.1 Soil Sampling, Preparation, and Analysis

A representative rubber-growing soil was obtained from Walailak University Farm (latitude 8° 38.145′ N longitude 99° 54.090′ E) at a depth of 5 to 30 cm. The sample was mixed and air-dried, and gravel and debris were removed by sieving through a 1 cm screen for pot trials. A portion of the sample was re-sampled, ground, and sieved through a 2 mm screen for chemical analysis. Soil pH and electrical conductivity (EC) were measured using 1:2.5 and 1:5 soil:water ratios, respectively. Electrical conductivity at the saturation point (ECe) was estimated by multiplying the EC by 6 (Shaw, 1999). Soil organic matter was analyzed using the Walkley and Black method. Exchangeable K, Ca, and Mg were extracted with 1 M NH_4OAc at pH 7.0, and their concentrations were analyzed via AAnalyst 800 atomic absorption spectrophotometry (AAS of PerkinElmer®). Available P was extracted using 0.03 M NH_4F in 0.10 M HCl (Bray II solution), and the concentration was analyzed using the molybdenum blue method. Available S was extracted using 0.01 M $K(H_2PO_4)_2$ solution, and the concentration was analyzed using turbidimetric method. Fe, Mn, Zn, and Cu were extracted using diethylenetriaminepentaacetic acid (DTPA) solution, and their concentrations were analyzed via AAS. B was extracted using hot 0.01 M $CaCl_2$, and the concentration was analyzed through the azomethine-H method (Jones, 2001; Jones, 2003).

2.2.2 Omission Pot Trials

A total of 8 kg of the dried soil sample was placed into a 25-cm diameter plastic pot. Except for the sample in the -Lime treatment, a 10.54 g of $Ca(OH)_2$ was mixed with the soil sample, depending on the lime requirement, to adjust the pH to 6. An amount of 2.50 litres of pure water was added to increase the soil moisture to 80% of the field capacity. The soil sample was then incubated for two weeks. Nutrient solutions were applied in 10 separate pots for the 10 treatments: All, -N, -P, -K, -Mg, -S, -Zn, -Cu, -B, and -Lime. Sufficient amounts of all test nutrients were applied into the pot containing complete treatment (All) (Table 1), and each nutrient was omitted in the corresponding minus treatments. The pots were placed randomly in a plastic-covered house. Three uniform seeds of a sweet variety of maize were sown in each pot, and the seedlings were thinned to maintain only one plant after two weeks. Soil moisture was maintained at 20 cbar to 40 cbar throughout the experiment by adding pure water. After 30 days of germination, the plant height, mid-leaf width, and leaf length were measured and the plant tops

were dried at 65°C and weighed. The effects of nutrient omissions were determined by comparing the relative growth with that of the All treatment.

Table 1. Nutrients, chemical forms and rates used for omission pot trials

Nutrients/Lime	Chemical forms	Nutrient rates (kg-element ha^{-1*})
N **	NH_4NO_3	400
P	Na_2HPO_4	120
K	KCl	175
Mg	$MgCl_2 \cdot 6H_2O$	75
S	Na_2SO_4	100
Zn	$ZnCl_2$	6
Cu	$CuCl_2 \cdot 2H_2O$	4
B	H_3BO_3	2
Lime (Ca)	$Ca(OH)_2$	Liming to pH 6.0

* Calculated from the area of a 25-cm diameter pot for maize and a 37-cm diameter pot for rubber.

** Split application:

Maize: Half-dose was applied at planting; the remaining dose was applied 21 days after germination.

Rubber: Half-dose was applied at planting; the remaining dose was applied 30 days later.

The omission pot trial using natural rubber as a test plant was performed in a manner similar to that used for maize. A total of 40 kg of the soil sample was placed into a 37 cm diameter plastic pot. The surface soil pH in the pots (0 to 15 cm) was adjusted to 6 using $Ca(OH)_2$, except the -Lime treatment sample. The samples were then incubated for three weeks. After the addition of nutrient solutions (Table 1), the budded stump of an RRIM 600 rubber clone at the one-whorl stage was planted in each pot. Soil moisture was maintained at 20 cbar to 40 cbar throughout the experiment. Additional nutrient solutions of the same rate were repeatedly applied at the fourth and eighth months. The height of the budded stem, the leaf width, the leaf length of the third petiole of the third whorl, and the biomass were measured at the ninth month. The relative growth at each treatment was calculated by comparing the results with those of the All treatment.

Differences among the treatments were analyzed using one-way ANOVA. Means which were significantly different were separated using Duncan's multiple range test (DMRT).

2.2.3 Field Experiment

A field experiment was conducted in a two-year-old RRIM 600 plantation growing on soil similar to that used for the omission pot trial. The experiment was laid out in a randomized complete block design with three treatments and three replications. Each treatment had 3 plots, and each plot comprised of 106 rubber trees. No fertilizer was applied for the control treatment (T1). A government-recommended 20-8-20 compound fertilizer was applied at a rate of 450 g $tree^{-1}$ on the first year and 460 g $tree^{-1}$ on the second year (T2). A nutrient correction based on the omission pot trial was performed by applying 18-46-0 at a rate of 375 g $tree^{-1}$ and $Ca(OH)_2$ at a rate of 440 g $tree^{-1}$ on the first year. Additional 18-46-0 application at a rate of 300 g $tree^{-1}$ and KNO_3 at a rate of 500 g $tree^{-1}$ were performed on the second year (T3). Leaf samples were collected at the third month after the new flush each year, and the samples were analyzed for nutrient concentrations. Trunk girth at 150 cm above the ground was measured every four months. Differences among the treatments were analyzed using one-way ANOVA. Means which were significantly different were separated using Least Significant Difference (LSD).

3. Results and Discussion

3.1 Soil Analysis and Omission Pot Trials

The soil was strongly acidic and had very low ECe, relatively low organic matter, very low available P, exchangeable K, Ca, and Mg, moderately extractable S, high extractable Fe and Mn, and relatively low Cu, Zn, and B (Table 2). The results indicated that soil pH, available P, exchangeable Ca, and extractable S, and Cu were lower than optimal ranges for rubber (Karthikakuttyamma et al., 2000; Suchartgul, 2011).

The omission pot trial using maize as a test plant revealed that the biomass from the -S, -Zn, and -B omission treatments were not significantly different from those of the All treatment. The biomass from the -N, -P, -K,-Mg -Cu, and -Lime treatments was low and significantly different from All treatment ($p < 0.05$). So, these factors were limiting for maize. Nevertheless, the biomass values of -Cu, -K, and -Mg treatments were higher than 80%. They were not limiting nutrients. Maize grown on the -P, -N and -lime treatments had a relative biomass of 3.8, 69.2, and 73.2% (Figure 1A). Leaf length, leaf width, and plant height showed similar responses. Leaf width was the most affected by soil nutrient status, whereas plant height seemed to be not affected (Figure 1B). These results indicated that S, B, Zn, K, Mg, and Cu were sufficient nutrients for maize. Biomass of the -S treatment was higher than the All, indicated that S should not apply on this soil. The N, P, and lime were limiting factors for maize. P was the most limiting nutrient. These results seemed to be alike soil analysis.

The omission pot trial using rubber as a test plant showed that the rubber shoot biomass in the -N, -P, -Cu, -Zn, and -Lime treatments tended to be lower than that in the All treatment. However, significant differences were found only in the -N and -P treatments. The -B, -S, -K, and especially the -Mg treatments yielded a higher biomass than the All treatment. Leaf length, leaf width, and plant height also showed similar responses. Plant height appeared to be the most affected vegetative character (Figure 2B). These results depicted that Mg, K, S, and B were greatly sufficient for a rubber, while the lime and Cu tended to adequate. The N and P were clearly insufficient for rubber (relative biomass values were 50.5 and 62.5%). The N was the most limiting nutrient.

This soil was extremely acidic (pH 3.8), indicating a highly weathered tropical soil. Lime omission decreased the biomass of maize and rubber by 27% and 14%, respectively (Figures 1A and 2A). These results confirmed that rubber tolerates soil acidity better than maize. The optimum soil pH for rubber was suggested to be lower than that for maize (Table 2). Karthikakuttyamma et al. (2000) suggested that rubber can be grown in a wide range of soil pH (3.8 to 8.0). Orimoloye et al. (2010) found that the pH values of Nigerian rubber-growing soils were 4.8-5.9 and suggested that the suitable soil pH should be in the range of 4.0 to 6.5 without any need for liming. Dharmakeerthi et al. (2005) suggested that the ideal soil pH in $CaCl_2$ for rubber-growing soil is 4.5 to 6.0, given that a higher pH may impose a problem on micronutrient availability. Roque et al. (2004) found that liming of the productive-phase rubber growing on a soil having pH 4.6 increased yield until the base saturation reached 75%, and foliar Ca concentration was 8 g kg^{-1}.

The amount of N did not meet the requirements of maize and rubber because of the low organic matter content. N is not the most limiting nutrient for maize, but it is for rubber. The different results may be attributed to the different N requirements of the two test plants. Rubber requires a larger amount of N because it was grown for a much longer period. N deficiency is a common problem for rubber-growing soils (Dharmakeerthi et al., 2005; Kungpisadan, 2009; Orimoloye et al., 2010). Growing rubber usually requires external sources of N, which may be leguminous cover crops or mineral fertilizers.

The -P treatment produced a relative biomass of only 4% and 63% for maize and rubber, respectively (Figures 1A and 2A). These results indicated that rubber tolerates P deficiency better than maize. P is the most limiting nutrient for maize, but no significant difference was found between P and N for rubber. Leaf length, leaf width, and plant height of maize and rubber exhibited similar values because P deficiency results in small leaves and stunting. Plant height appears to be the most affected vegetative character for rubber (Figure 2B). Nilnond et al. (1995) also found similar P deficiency in a mangosteen-growing soil in southern Thailand. Acidic soils contain a large amount of aluminum (Al) and iron (Fe). Thus, negatively charged inorganic P is readily precipitated as highly insoluble Fe- or Al- phosphates, which are poor sources of P for higher plants (Stevenson, 1986). The secretion of citric acid in rubber roots may enhance the P uptake. Therefore, rubber can grow better than many crops when P is immobilized in the soils (Onthong & Osaki, 2006). Akpan et al. (2007) reported that both RRIM 600 and PR 107 rubber clones gave better yields in soils with higher available P in Nigeria.

The Cu concentration in the soil used for present study was lower than the optimum range (Table 2). The biomass of both maize and rubber was reduced to 83% when Cu was omitted (Figures 1A and 2A). Therefore, Cu is also one of the limiting nutrients for the soil. The application of Cu should enhance rubber growth, but excessive Cu adversely affects the oxidation process of rubber (Pushparajah et al., 1988). Nilnond et al. (1995) and Lim et al. (1993) also reported the occurrence of a Cu deficiency in mangosteen- and neck orange- growing soils in southern Thailand.

The concentrations of exchangeable K and Mg were lower than the optimum ranges for the general recommendation, but they were within the ranges for rubber (Table 2). The omitted K and Mg treatments tended to reduce the growth of maize but allowed for better growth of rubber (Figures 1 and 2). K, Mg, and Ca are mutual antagonists (Tisdale et al., 1999; Maneepong, 2009). Therefore, an imbalanced application of these nutrients may

affect rubber growth. The application of K and Mg fertilizers should be carefully recommended, even though their concentrations are lower than the optimum ranges.

The concentrations of extractable S, Zn, and B were within the optimum ranges (Table 2). The omission treatments of these nutrients did not result in any significant difference in growth for both maize and rubber compared with the complete treatments. Rubber-growing in the soil used in this study requires supplementation of these nutrients to compensate for their loss.

Table 2. Chemical properties of the soil and their optimal levels for rubber, maize, and plants in general

Properties	Soil used for study	Optimum range for rubber	Optimum range for maize	Optimum range for plants in general
pH	3.8	4.0-6.5[a]	5.0-5.5[c]	5.5-6.5[f]
ECe (mS cm^{-1})	0.20	-	-	< 2[f]
OM (%)	1.25	1.0-2.6[b]	2-3[d]	1.5-2.5[f]
P (mg kg^{-1})	4.7	10-25[a]	8-11[c]	10-15[f]
K (mg kg^{-1})	62	50-125[a]	81-120[c]	91-140[g]
Mg (mg kg^{-1})	35	10-25[a]	> 34[d]	151-350[g]
Ca (mg kg^{-1})	132	50-600[b]	320-800[d]	1001-2000[g]
S (mg kg^{-1})	14	25-35[b]	7-12[c]	6-12[h]
Fe (mg kg^{-1})	85	30-90[b]	2.5-5.0[e]	2.1-5.0[g]
Mn (mg kg^{-1})	16	2-4[b]	1.0-2.0[e]	1.0-20.0[g]
Cu (mg kg^{-1})	0.14	0.5-1.5[b]	0.12-2.5[e]	2.6-5.0[g]
Zn (mg kg^{-1})	0.5	0.5-1.5[b]	0.25-2.0[e]	0.5-1.0[g]
B (mg kg^{-1})	0.3	0.3-0.7[b]	0.1-2.0[e]	1.1-2.0[g]

Sources: [a]Karthikakuttyamma et al. (2000); [b] Suchartgul (2011); [c]Tisdale et al. (1999); [d]FMANR (1990); [e]Cox (1987); [f]Kheoruenromne (2001); [g]Jones (2003); [h]Landon (1996).

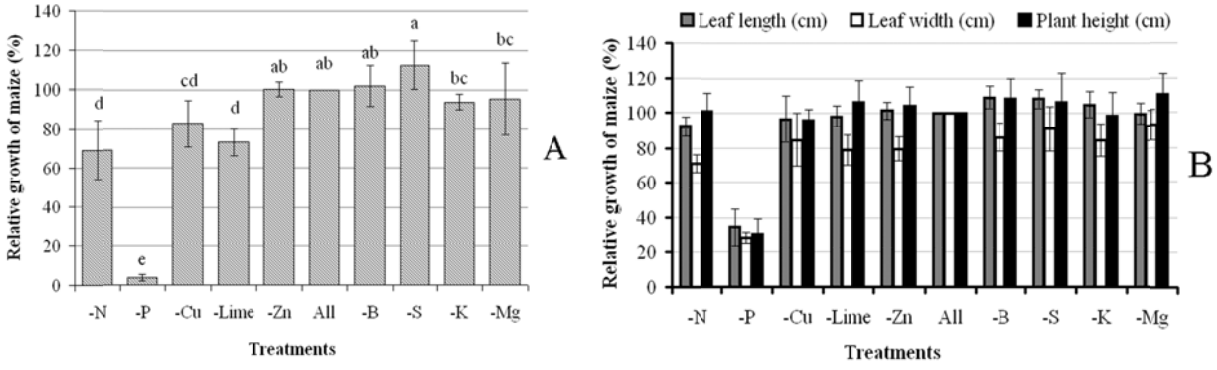

Figure 1. Relative growth of maize in various nutrient omission treatments of the study soil: (A) relative biomass (the same letters on various columns do not differ significantly on 5% probability level by Duncan's multiple range test (DMRT), and (B) relative vegetative growth characters

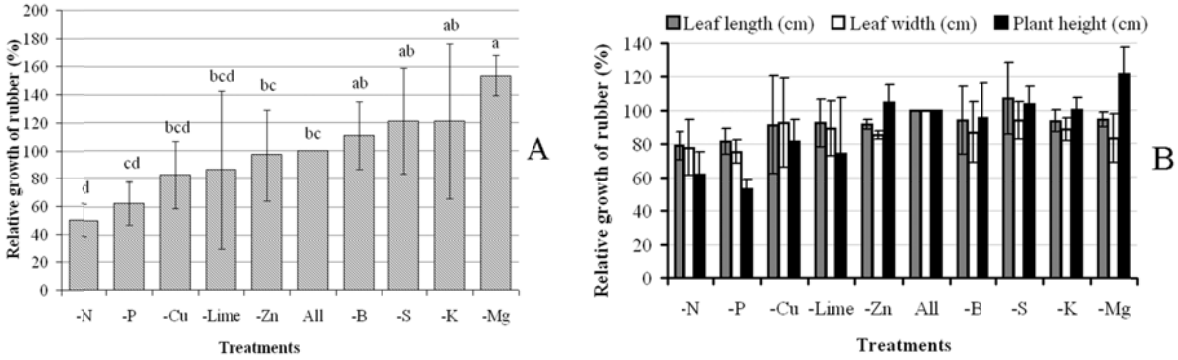

Figure 2. Relative growth of rubber in various nutrient omission treatments of the study soil: (A) relative biomass (the same letters on various columns do not differ significantly on 5% probability level by Duncan's multiple range test (DMRT),and (B) relative vegetative growth characters

3.2 Field Experiment

The concentrations of several macro-nutrients in rubber leaves obtained from the experimental field are shown in Table 3. N concentration of all treatments were lower than the optimal ranges for rubber (30-38 g kg^{-1}; Suchartgul et al., 2012 and 33.1-37.0 g kg^{-1}; Kungpisadan, 2005) and decreased 14, 10, and 8% over two year in T1, T2, and T3 fertilization. The results indicated that status of N in this soil was very low and insufficient for the rubber. Using T2 (20-8-20; 41 kg-N ha^{-1} $year^{-1}$) and T3 (Omission-based; 50 kg-N ha^{-1} $year^{-1}$) could slightly decrease the N status of leaves. The result was in accordance with Dakora & Donald (2002); Dharmakeerthi et al. (2005); Kungpisadan (2009) and Orimoloye et al. (2010). They stated that N deficiency is a common problem for rubber growing soils. Pushparajah (1994) suggested that N should be applied 300 kg-N ha^{-1} $year^{-1}$ for immature RRIM 600 clone, if it was cultivated in infertile soil (N concentration was < 1 g kg^{-1}) and leaf N content was 28-30 g kg^{-1}. N fertilization at a rate of 250 kg ha^{-1} $year^{-1}$ for immature rubber was recommended for low K soils in Thailand. The T2 and T3 of this experiment were used lower N than those suggested amounts, and they may insufficient for rubber requirement. The results accorded with omission pot trial, which showed N was the limiting nutrient both for maize and rubber and application rate of N should be increased from 0.25 to 0.50 times of the basal rate. The P concentration was found in the range of 2.0-2.7 g kg^{-1} in rubber leaves of all treatments. In June 2011, leaf P concentrations found in T2 and T3 significantly differed from T1 ($p<0.05$) (Table 3). The sufficient range for rubber was 2.5-3.0 g kg^{-1} (Suchartgul et al., 2012). These results showed that using fertilizers like T2 and T3 remarkably increased the concentration of P. Meaning that, the rubbers were still responded to P of T2 and T3 fertilization and the response was nearly accorded to the omission trial assessment than chemical analysis. P uptake was dependent on soil moisture. Optimum soil moisture level makes P available to plants but excess of moisture reduces O_2 thus limiting root growth and lowering P uptake (Potash & Phosphate Institute [PPI], 2003). These results indicated that P fertilizer application based on omission pot trial assessment is more suitability than soil analysis. But, rate of P application should be decreased from 1.0 to 0.50 times of basal rate of P in omission pot experiment. The K concentration in rubber leaves were found in the range of 10-12.1 g kg^{-1} and was not significant difference among treatments, except at June 2011 found lowest value in T3 (Table 3). The leaf K concentrations of all treatments were sufficient for a rubber (10-15 g kg^{-1}; Suchartgul et al., 2012; Karthikakuttyamma et al., 2000). The result confirm to soil analysis and omission pot trial. The Ca concentration in rubber leaves was found in the range of 4-14.2 g kg^{-1}. Leaf-Ca of the first year was much lower than the sufficient value (10-15 g kg^{-1}, Suchartgul et al., 2012). The concentrations increased in every treatment although no lime was applied. However, the leaf-Ca significantly increased ($p<0.05$) on the lime application plots (T3) than no lime (T1 and T2). The result indicated that rubber required Ca, which corresponded to the omission trial and chemical soil analysis results (Figures 1 and 2 and Table 3). Tropical soils are usually deficient in Ca (Nilnond et al., 1995; Yingjajaval & Bangjan, 2006) thereby, Ca addition to rubber growing soil is necessary. Using a compound fertilizer for rubber without any Ca may result in a lack of Ca in rubber growing soil in the future. The leaf-Mg content was found in the range of 2.0-3.4 g kg^{-1} of all treatments and was within optimal range for rubber (2.1-2.5 g kg^{-1}; Kungpisadan, 2005). The contents were not significantly different ($P > 0.05$) among treatments. T1 seemed to be lower than the both T2 and T3. The results indicated that Mg concentration in this soil was at sufficient level for rubber, and T2 and T3

fertilization promoted Mg uptake but using lime needs to take into account nutrients balance between K, Ca, and Mg uptake (Neilsen & Edwards, 1982).

Mean girth of the rubber trees at beginning of the experiment was 9.50 ± 1.80 cm. After 4 months of fertilization until end of the experiment, the girth increments were significantly differed between T1 and T2, T3 ($P < 0.05$). The girth increment of T1 was remarkably lower than T2 and T3 throughout the experiment. The girth increment of T3 was slightly higher than T2 in first year, but it was lower in the second year, and increase over again in the third year. The girth increments of T3 and T2 were not significant difference ($P > 0.05$) at the end of the experiment (Figure 4), and mean girth of T1, T2, and T3 were 26.64 ± 1.44, 31.01 ± 1.17, and 31.01 ± 0.96 cm, respectively. Application of lime and a high rate of P did not improve rubber growth over the government-recommended fertilization. This result may cause from limitation of N for the omission-based fertilization.

Nutrients assessment by chemical soil analysis and omission pot trials showed good agreement to each other. Analytical results of N, P and pH found to be low, and growth of the indicator plants showed the same trend (Table 4).

Table 3. Nutrient concentrations in rubber leaves obtained from the experimental field at the third month after new flush

Nutrients	Treatments	Sampling months and years		
		July 2009	July 2010	June 2011
N (g kg^{-1})	T1 (Control)	28.5 ± 3.6^{ns}	26.3 ± 1.3^{ns}	24.5 ± 0.3^{ns}
	T2 (20-8-20)	30.3 ± 0.5^{ns}	27.7 ± 0.9^{ns}	27.2 ± 0.7^{ns}
	T3 (Omission-based)	29.5 ± 0.5^{ns}	27.9 ± 1.3^{ns}	26.9 ± 1.6^{ns}
P (g kg^{-1})	T1 (Control)	2.0 ± 0.0^{b}	2.0 ± 0.2^{ns}	2.3 ± 0.1^{b}
	T2 (20-8-20)	2.2 ± 0.1^{a}	2.1 ± 0.2^{ns}	2.6 ± 0.1^{ab}
	T3 (Omission-based)	2.1 ± 0.1^{b}	2.2 ± 0.2^{ns}	2.7 ± 0.2^{a}
K (g kg^{-1})	T1 (Control)	10.0 ± 0.3^{ns}	11.2 ± 0.1^{ns}	12.0 ± 0.2^{a}
	T2 (20-8-20)	10.5 ± 0.5^{ns}	12.1 ± 1.0^{ns}	11.9 ± 0.3^{a}
	T3 (Omission-based)	10.1 ± 0.3^{ns}	11.7 ± 0.7^{ns}	11.1 ± 0.2^{b}
Ca (g kg^{-1})	T1 (Control)	4.7 ± 0.2^{ns}	9.0 ± 1.7^{ns}	10.6 ± 0.7^{b}
	T2 (20-8-20)	4.0 ± 0.9^{ns}	9.5 ± 1.0^{ns}	11.9 ± 2.5^{b}
	T3 (Omission-based)	4.6 ± 0.6^{ns}	9.7 ± 0.9^{ns}	14.2 ± 1.0^{a}
Mg (g kg^{-1})	T1 (Control)	2.0 ± 0.2^{b}	3.1 ± 0.4^{ns}	2.9 ± 0.5^{ns}
	T2 (20-8-20)	2.1 ± 0.2^{ab}	3.3 ± 0.1^{ns}	3.3 ± 0.5^{ns}
	T3 (Omission-based)	2.2 ± 0.1^{a}	3.2 ± 0.2^{ns}	3.4 ± 0.6^{ns}

Means followed by equal letters in the columns do not differ by the Least Significant Difference at 5% probability.

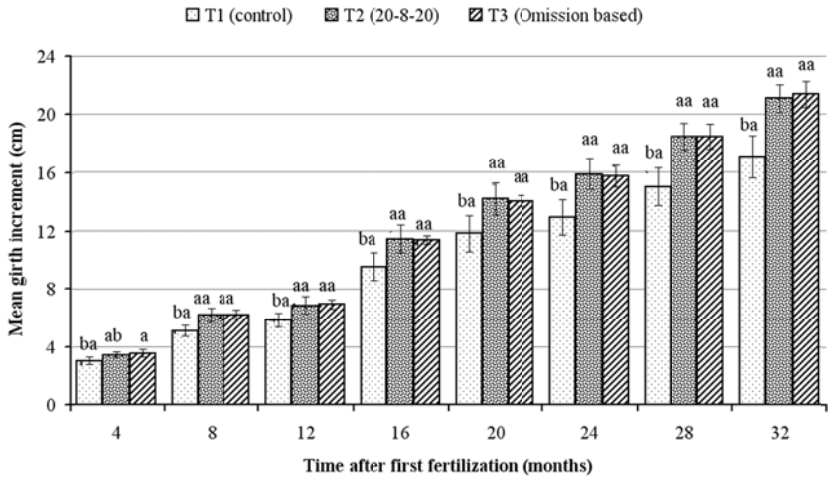

Figure 4. Mean girth increment of rubber trees in the field experiment with no-fertilization (T1), government-recommended (T2) and omission-based fertilization (T3)

Table 4. A comparison between soil analysis, omission pot trial, and rubber leaf nutrients contents adjusted with omission-based fertilizer in a two-year-old RRIM 600 rubber plantation

Soil properties	Soil analysis*	Omission trial (maize as test plant)*	Omission trial (rubber as test plant)*	Leaf nutrient contents**
pH	-	-	-	
N		-	-	+
P	-	-	-	+
K	+	+	+	0
Ca	-	-	-	+
Mg	+	+	+	
S	-	+	+	
Cu	-	+	+	
Mn	+	+	+	
Zn	+	+	+	
Fe	+	+	+	
B	+	+	+	

Note:

* column; minus (-) means that limiting for rubber, plus (+) means that sufficient for rubber.

** column; minus (-) means that decreasing leaf nutrient content at the end of experiment, zero (0) means that non responded, and plus (+) means that decreasing leaf nutrient content at the end of experiment.

4. Conclusions

Nutrient assessment through an omission pot trial and a soil analysis showed the same results. However, the omission pot trial provided the order and magnitude of the nutrient deficiency and more easily to determine the most limiting nutrient. Leaf length, leaf width, and plant height also responded well to the nutrient status. Therefore, they may be used as growth indices instead of the biomass during the growing period.

The pot trial using maize and rubber showed that N, P and lime were limiting factors for the studied soil. However, order of limiting for maize was P > N > lime, whereas for the rubber was N > P > lime. Rubber in the experimental field responded to N and P fertilization, corresponded to the pot trial. Fertilization according to Thai government recommendation and the pot trial could be increase the rubber girths over non-fertilization, but no significant difference between the two methods. A high rate of P application did not improve the rubber growth, although it was a limiting factor. Lime application also did not improve growth rate of the rubber.

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