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Determination of Nitrogen and Phosphorus Requirement of the RRIM 600 and RRIT 251 Young Rubber Trees

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Abstract

Young rubber trees require sufficient nutrients to ensure successful planting and optimization of fertilizer cost. This study focused on the nitrogen and phosphorus requirement of the RRIM 600 and RRIT 251 young rubber trees, aged 6 - 9 months. The study was conducted using a complete randomized design (CRD) with 8 replications. The budded stumps of both clones were planted in polybags with charcoal as plant materials. Each clonal variety was distributed into 3 drip-irrigated hydroponic recirculating nutrient solution systems. The experiment started when young rubber trees had the first whorl with mature leaves. Solutions in the systems were sampled and analyzed for nitrogen and phosphorus content, and the tank volume was measured one hour after each watering event every 4 days through the experimental period. Results showed that nitrogen and phosphorus uptakes of RRIM 600 and RRIT 251 were not different. Total nitrogen use of the clones was 1191.08 ± 18.69 and 1241.09 ± 21.96 $mg.plant^{-1}$, respectively, and total phosphorus use of the clones was 112.52 ± 5.22 and 131.81 ± 8.03 $mg.plant^{-1}$, respectively. The RRIT 251 young rubber trees had higher nitrogen use efficiency than that of the RRIM 600 as was evident from their stem height ($P < 0.05$), 2.68 ± 0.16 $cm.g^{-1}$ and 1.67 ± 0.22 $cm.g^{-1}$, respectively. As a result, the nitrogen cost of an RRIT 251 rubber tree was lower than the RRIM 600 one around one fold or 0.006 USD. Total nitrogen and phosphorus costs for producing a young rubber tree of each clone were 0.012 and 0.008 USD, respectively.

Keywords: RRIM 600, RRIT 251, nitrogen and phosphorus uptake, nutrient cost

Introduction

Rubber is one of the important commodity crops and has contributed much to the nation's economy as Thailand is the largest producer and exporter of natural rubber in the world, 6 billion USD or 36.5 % of total rubber export [1]. The main planting area is in the southern region of the country, approximately 18.78 billion m^2 or 68.2 % of the planted area nationwide [2]. The RRIM 600 clones represent approximately 80 % of total rubber tree planted. The clones have been produced and field tested to improve the yield with several selection criteria, including vigor, resistance to diseases, resistance to wind, fewer and higher branches, and bark thickness. The yield is not only the latex, but also the timber from the rubber trees which is in high demand as well [3]. The RRIT 251 clone is a new promising Thai high-yielding clone [4] that is widely used for new planting or replanting in Thailand [5]. The trees from these clones are known for their performance, rapid growth with dense canopy, and high latex yield. Due to the canopy characteristics, the RRIT 251 may require more nutrients for its growth than the RRIM 600 does. Therefore, the RRIT 251 clone has an average growth during the immature period that is lower than RRIM 600 [6]. Nutrients are the major limiting factor in plant growth, and the nutrient requirement of rubber trees is different among the clones and among the same clone at different stages in the life span [7-9]. Therefore, the RRIM 600 and RRIT 251 young rubber trees require a review of the fertilizer requirement in order to optimize plant growth.

The most important nutrients for rubber trees are nitrogen, phosphorus, potassium, and magnesium. Among of these nutrients, nitrogen and phosphorus are essential elements influencing rubber tree growth and latex production [10-12]. Nitrogen deficiency will lead to reduced leaf size and tree girthing, and eventually to stunting of the tree. Phosphorus deficiency results in young unbranched trees, small leaves and stunting. The symptoms are first found in leaves in the middle whorl up to the upper whorl and a considerable defoliation may also occur [7,13]. Application of fertilizers at high levels can degrade soil and water resources in the long term, leading to the loss of the ecosystem and a decrease in agricultural sustainability. Furthermore, inefficient use of fertilizer leads to economic loss in a form of fertilizer cost. In the early growth stage, 10 - 20 % of young rubber trees normally die or thin out [8]. Replacement rubber trees have similar growth stage as the ones which have already been planted. Therefore, nutrient management is needed to ensure successful planting and optimization of the fertilizer cost [3]. Practically, it is difficult to provide adequate nutrient supply for plants since there are many factors involved. This study used the hydroponic recirculating nutrient solution system and planted young rubber trees in a greenhouse in order to avoid undesired factors and to ensure non-limiting nutrients supply. This system has been successfully used for the nutrient requirement testing of poplar [14], maple, and walnut [15]. Since fertilizer recommendations for RRIM 600 and RRIT 251 young rubber trees are currently not available, this article describes nitrogen and phosphorus uptake and common recommendations for the young clones. Data on crop responses on nitrogen and phosphorus has led to a proposed revision to nutrient requirement and its efficiency.

Materials and methods

Plant materials

Plant materials and growth conditions

Rubber trees (*Hevea brasiliensis*) clonal varieties RRIM 600 and RRIT 251 originating from budded stumps were planted in polybags (6×12 in) with charcoal (1×1 cm). Each clonal variety was distributed into 3 drip-irrigated hydroponic recirculating nutrient solution systems, and each system contains 8 plants. In relation to the solution recirculation system, the 50 l nutrient solution was automatically drip-irrigated and it was recirculated for 20 min, 3 times a day to ensure non-limiting supply of water and nutrients. The composition of nutrients with nitrate was (mmol.l^{-1}) 1.82 NO_3^-, 0.19 $H_2PO_4^-$, 0.24 SO_4^{2-}, 1.00 K^+, 0.39 Ca^{2+}, 0.355 Mg^{2+}, where micro elements were renewed every 8 days [14]. The experiment started when the young rubber trees contained the first whorl with mature leaves. The number of leaves, girth, and plant height were collected every 4 days.

Nitrogen and phosphorus uptake

Nutrient uptake was computed from the temporal variation in the quantity of nutrient within the solution recirculation system [16]. Nutrient solutions were sampled for 0.06 l and the tank volume was measured one hour after each watering event, at 9 am every 4 days. Nitrogen and phosphorus were analyzed using the kjeldahl method and ascorbic acid method, respectively. Then, the quantity of nutrients uptake was estimated by a modified model of Beaujard and Hunault [16];

$$\text{Nutrient uptake} = \frac{1}{N}\left(\sum_{j=1}^{m}\sum_{i=1}^{n_j}[C_{i,j}V_{i,j} - C_{i+1,j}V_{i+1,j}]\right) \quad (1)$$

Nutrient uptake (mg.plant^{-1}); $C_{i,j}$ (mg.l^{-1}) and $V_{i,j}$ (l) are nutrient concentration and solution volume in the tank at the ith measurement after the jth nutrient solution was renewed (the 1st measurement being the initial measurement after each renewal), n_j number of time that measurements are taken after the jth renewal, m number of renewals (the 1st renewal being the initial setup) and N is the number of plants in the recirculation system.

In order to estimate nutrient use efficiency and its costs, the nutrient use efficiency (NUE) was obtained from a modified equation of the nitrogen use efficiency function which was suggested by Hirel *et al*. [17]. NUE is defined as the ratio of the rubber tree growth (G; number of leaves, girth, and stem height) and nutrient uptake (U; nitrogen and phosphorus) during the experimental period. Then, nutrient use efficiency was monetarily estimated by its market price.

$$\text{NUE} = \frac{G}{U} \tag{2}$$

Data analysis

All data were subjected to the analysis of variances to determine the significance of difference in clonal varieties. Differences between clonal varieties were assessed by independent T-test at the 0.05 level of probability. Linear correlation between nitrogen and phosphorus uptake were considered significant when the probability is at the 0.05 level. All statistical analyses in this study were performed by using SPSS.

Results and discussion

Nitrogen and phosphorus uptake

Nitrogen and phosphorus uptake dynamics depended on available concentration of both elements and the pH of the nutrient solution in drip-irrigated hydroponic recirculating nutrient solution systems [15]. Nitrogen and phosphorus concentrations during the experiment were 21.93 - 1.87 mg.l^{-1} (**Figure 1A**) and 6.45 - 5.38 mg.l^{-1} (**Figure 1B**), respectively. The pH of the nutrient solution during the experiment was about 6.4 - 7.9 which ensures a strong uptake. Plants grow equally well between pH 5 and 7, if nutrients do not become limited. The problem is reduced nutrient availability at high and low pH. The availability of nutrients is optimized at a slightly acidic pH. The availabilities of Mn, Cu, Zn and especially Fe are reduced at higher pH, and there is a small decrease in availability of P, K, Ca, Mg at lower pH. Reduced availability means reduced nutrient uptake [18-20].

The dynamic curves of nitrogen and phosphorus uptake of RRIM 600 and RRIT 251 were not statistically different suggesting that both rubber trees could uptake nutrients during the experimental period. Nitrogen uptake was about 1191.08±18.69 and 1241.09±21.96 mg.plant^{-1} respectively (**Figure 2A**). Phosphorus uptakes at the start and the end of the experiment were 112.52±5.22 and 131.81±8.03 mg.plant^{-1}, respectively (**Figure 2B**).

For clonal varieties RRIM 600 and RRIT 251, nitrogen and phosphorus uptakes were strongly and significantly correlated during the study period (**Figure 3**). This correlation could be mediated by young rubber tree growth which requires a large ratio between nitrogen and phosphorus uptakes [10-12]. Nitrogen is a constituent of all proteins and thus of all protoplasm and is required in relatively large quantities. It is also a constituent of chlorophyll. On the other hand, phosphorus is a constituent of nucleic acids required for the development of meristematic tissue and is a very important part in enzyme systems. Phosphorus compounds often act as suppliers of energy for specific reactions, providing a link between the energy released in respiration and reactions requiring energy [7,21,22].

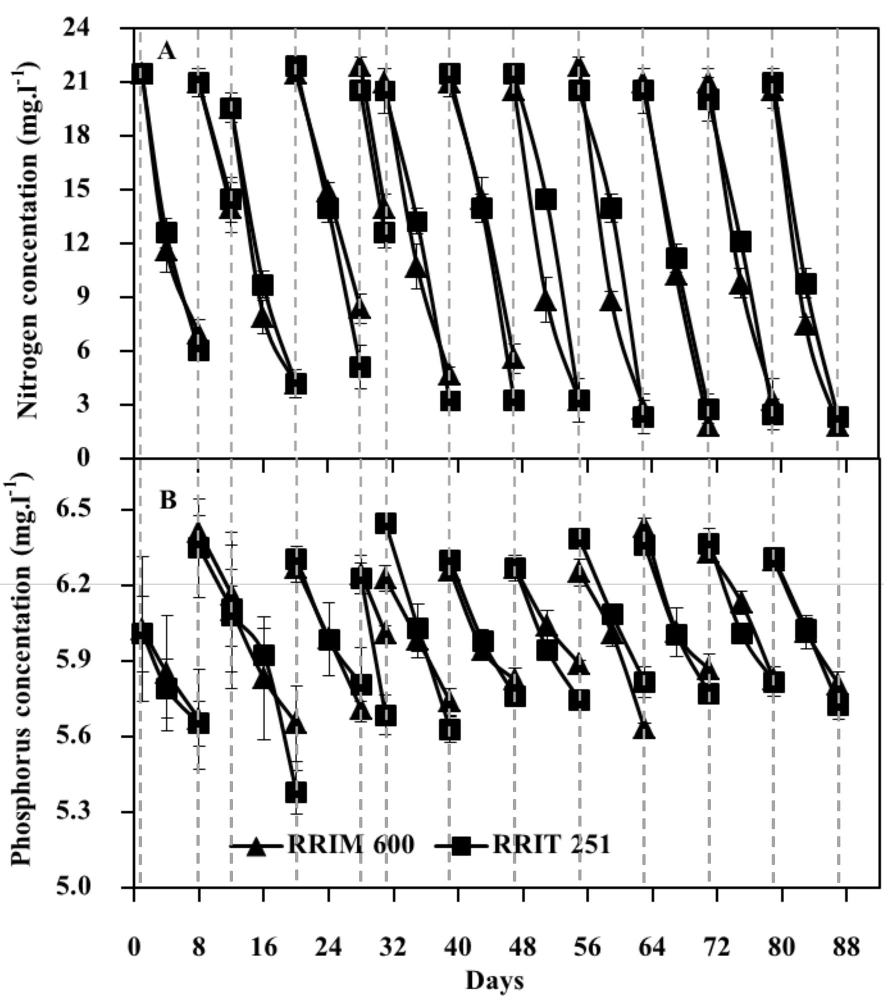

Figure 1 Availability of nitrogen (A) and phosphorus (B) concentrations in the solution recirculation system of young rubber trees clonal varieties RRIM 600 (▲) and RRIT 251(■). The values represent the mean±S.E. of 3 recirculating nutrient systems. The dashed lines indicate the day in which the nutrient solution was renewed.

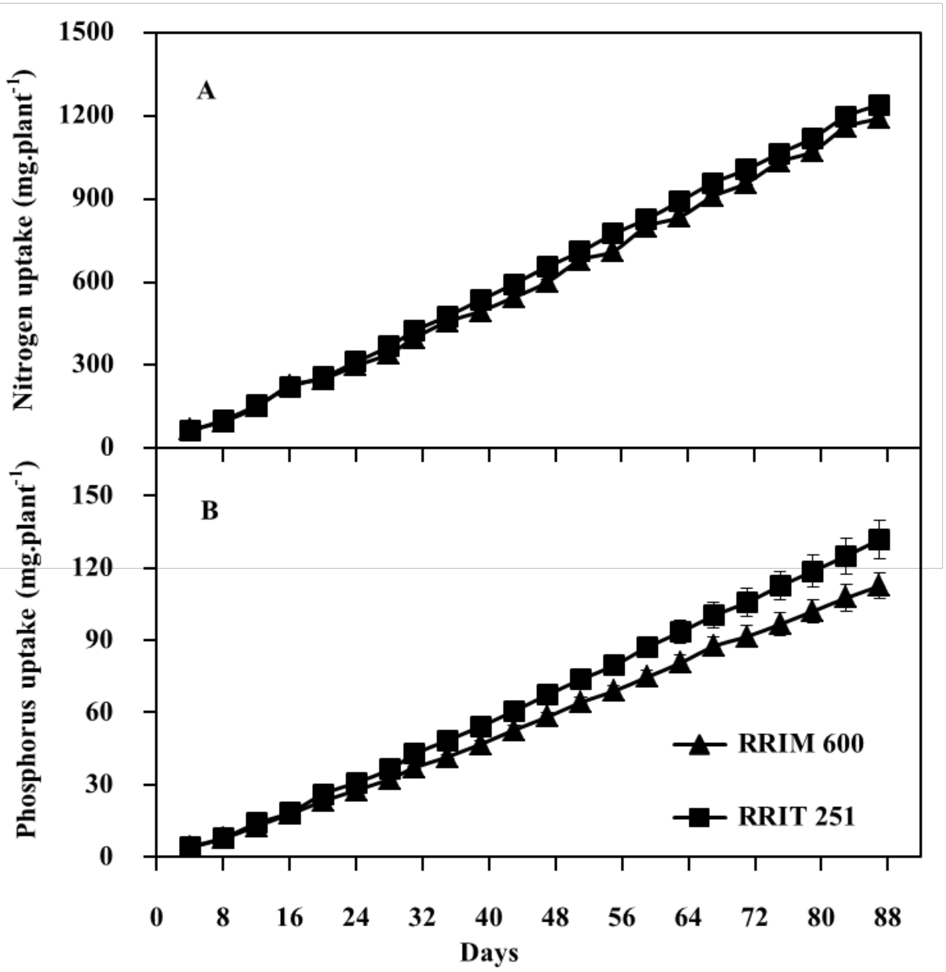

Figure 2 Cumulative nitrogen (A) and phosphorus (B) uptake of young rubber trees clonal varieties RRIM 600 (▲) and RRIT 251(■). The values represent the mean±S.E. of 3 recirculating nutrient systems.

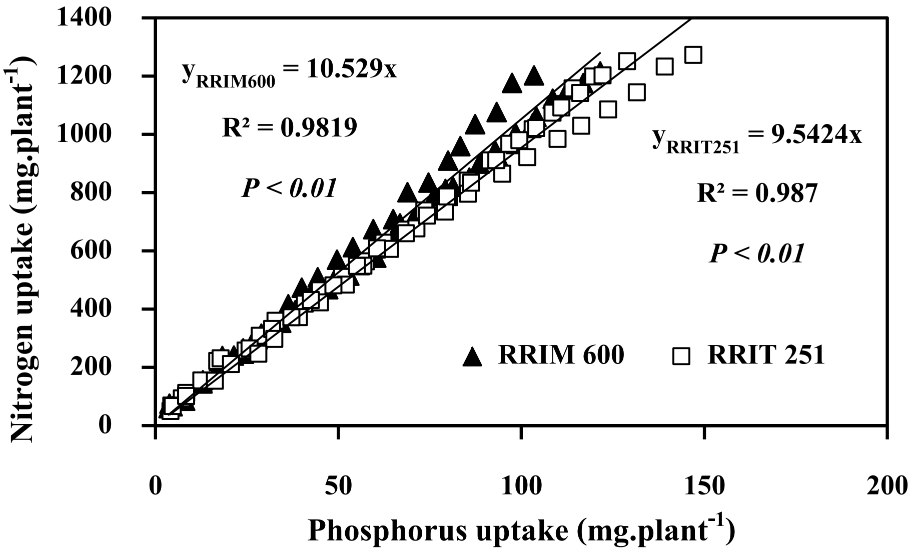

Figure 3 Linear correlation between nitrogen and phosphorus uptake of young rubber trees clonal varieties RRIM 600 (▲) and RRIT 251 (□).

Plant growth

A statistical analysis showed that the numbers of leaves per plant and girths of clonal varieties RRIM 600 and RRIT 251 were not different (**Figure 4**). However, the numbers of leaves per plant and girths of both trees increased about 11 - 16 leaves and 1.12 - 1.23 cm during the experiment, respectively. Similarly, stem heights of both rubber trees were not different until 67 days. After that the stem of RRIT 251 increased significantly faster than that of RRIM 600 ($P < 0.05$). Stem heights of RRIT 251 and RRIM 600 increased during the study period by 33.3±2.44 and 19.83±2.35 cm, respectively.

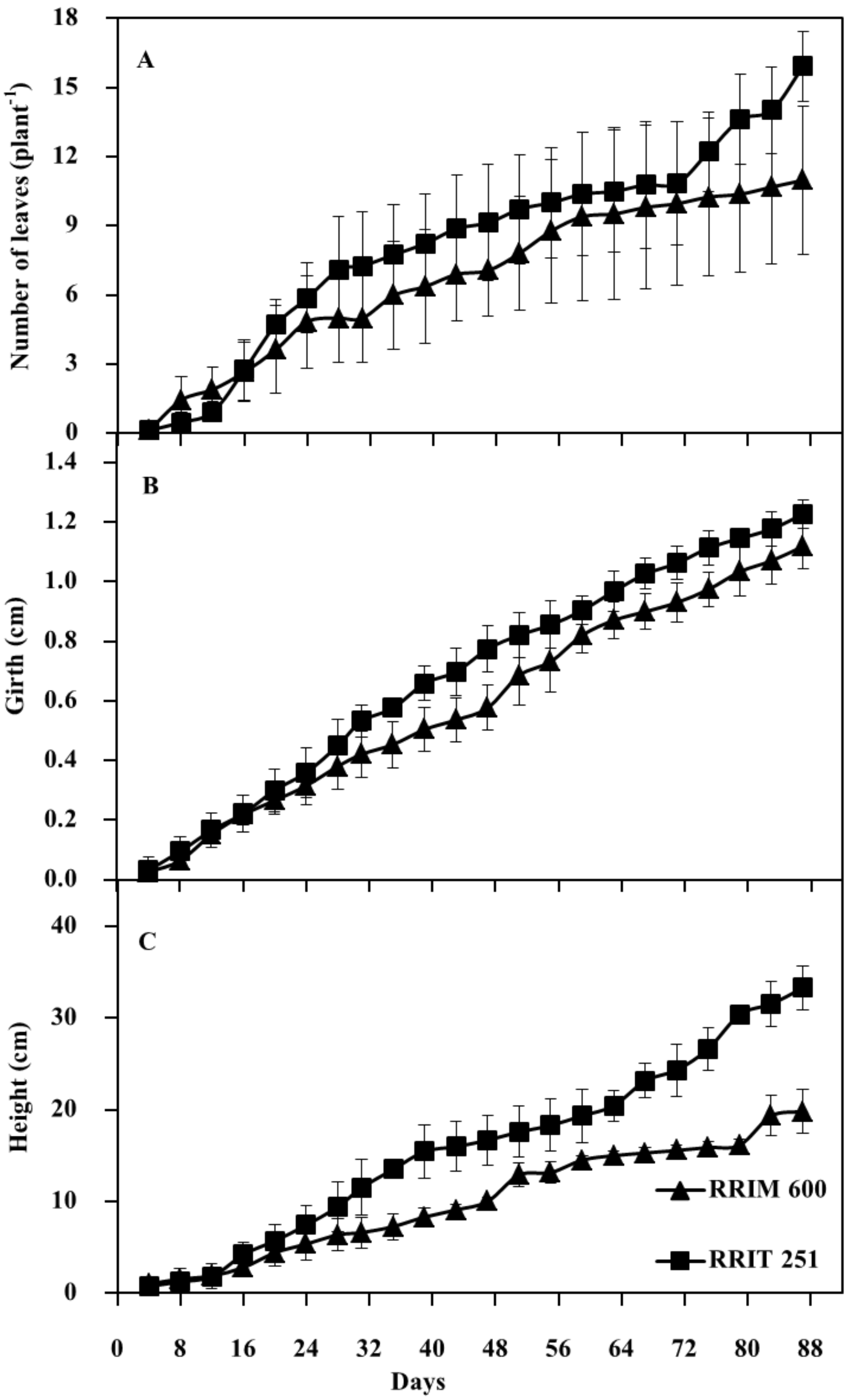

Figure 4 Number of leaves (A), girth (B) and height (C) increment of young rubber trees clonal varieties RRIM 600 (▲) and RRIT 251(■). The values represent the mean±S.E. of 24 plants.

Nutrient use efficiency and costs

Nutrient use efficiency is defined as the ratio of the growth of RRIM 600 and RRIT 251 rubber trees and the nutrient uptake during the experimental period. Data on growth such as the number of leaves, girth, and stem height were taken and nutritional status of nitrogen and phosphorus was analyzed. Findings showed that, in terms of nitrogen use efficiency, the numbers of leaves and girth of both clones were not significant. The trees that uptook 1 g of nitrogen could produce about 1 leaf, 0.1 cm of girth, and 2.68 cm of height, respectively. However, the stem height of RRIT 251 was 2.68 ± 0.16 $cm.g^{-1}$ higher than that of RRIM 600, which was 1.67 ± 0.22 $cm.g^{-1}$. There was no significant difference for all 3 indicators in terms of the phosphorus use efficiency between RRIT 251 and RRIM 600 young rubber trees. The number of leaves, girth, and stem height were 10 - 12 leaves g^{-1}, 0.94 - 0.99 $cm.g^{-1}$ and 17.84 - 25.25 $cm.g^{-1}$, respectively (**Table 1**).

Table 1 Nutrients use efficiency of RRIM 600 and RRIT 251 young rubber trees.

	Nitrogen use efficiency			**Phosphorus use efficiency**		
	NL ($NL.g^{-1}$)	**Girth ($cm.g^{-1}$)**	**Height ($cm.g^{-1}$)**	**NL ($NL.g^{-1}$)**	**Girth ($cm.g^{-1}$)**	**Height ($cm.g^{-1}$)**
RRIM 600	0.93 ± 0.29	0.09 ± 0.01	1.67 ± 0.22	12.03 ± 0.42	0.99 ± 0.02	17.84 ± 2.66
RRIT 251	1.28 ± 0.10	0.10 ± 0.01	2.68 ± 0.16	9.70 ± 2.79	0.94 ± 0.09	25.25 ± 0.74
T-test	ns	ns	*	ns	ns	ns

NL= Number of Leaves

As suggested by RRIT (2001) [23], young rubber trees in the nursery are ready and appropriate for transplant to the field when the plants have either 2 - 3 whorls or 6 - 7 whorls of leaves or have at least 20 cm height. To attain that height, young rubber trees RRIM 600 and RRIT 251 require nitrogen and phosphorus at least 11.98, 1.12, 7.46 and 0.79 g, respectively.

Urea [$CO(NH_2)_2$] (N-P-K; 46-0-0) and diammonium phosphate [$(NH_4)_2HPO_4$] (N-P-K; 18-46-0) were supplied as fertilizer in this study instead of other nutrient forms because they are inexpensive [24], and commonly used in agricultural plant production in Thailand. In addition, the nutrient forms are recommended as a straight fertilizer by the Ministry of Agriculture and Cooperatives in Thailand. Therefore, to achieve better efficiency of urea and diammonium phosphate fertilization, RRIM 600 should be supplied with both nutrients at 23.87 and 5.57 g, respectively, and RRIT 251 at 14.70 and 3.93 g, respectively. Moreover, the fertilizers should be applied monthly to budded stumps after bud break for 4 - 5 months. In 2016, an average retail price per ton of urea and diammonium phosphate was 378.29 and 584.74 USD [25]. Therefore, the costs of nitrogen supplied for a young rubber tree RRIM 600 and RRIT 251 to be ready for transplanting are 0.009 and 0.006 USD, respectively. The cost of diammonium phosphate supplied for a young rubber tree of both clones is 0.003 and 0.002 USD, respectively.

Conclusions

From the data obtained on the number of leaves, girth, and stem height, it is shown that nitrogen and phosphorus uptakes for growth of the RRIM 600 and RRIT 251 young rubber trees were not significantly different. The nutrient uptakes of both clones were strongly correlated which may be mediated by the high growth demand of the young rubber trees. The nitrogen use efficiency of RRIT 251 was higher than that of RRIM 600 rubber trees when the stem height is used as a growth indicator. From this result, either nitrogen supplied or its cost for RRIT 251 rubber trees was lower than that of RRIM 600. However, phosphorus use efficiency for each clone was about the same. Findings suggest that nutritional supply consideration would create significant benefit for rubber producers in terms of nutritional optimization and efficient fertilizer costs. This study is considered as a preliminary approximation, and the next step of the research will be to collect more data on major and minor nutrients and extend to field testing. Furthermore, it is generally well known that most plants uptake urea, ammonium and nitrate by different mechanisms, and the response of plants for each nitrogen form is not the same [26-28]. Therefore, future research should compare the effect of nitrogen forms on plant growth.

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References

[1] The World Factbook. Field Listing: Exports - Commodities, Central Intelligence Agency. Available at: http://www.worldstopexports.com/natural-rubber-exports-country, accessed March 2016.
[2] Office of Agricultural Economic. Rubber statistic. *Agric. Prod. Forecast J.* 2015; **29**, 1-19.
[3] SJ Mokhatar, NW Daud and CF Ishak. Response of *Hevea Brasiliensis* (RRIM 2001) planted on an oxisol to different rates of fertilizer application. *Malays. J. Soil Sci.* 2012; **16**, 57-69.
[4] P Susewee. *RRIT 251: A New Thai High-Yielding Hevea Clone*. The Rubber International Magazine, Bangkok, Thailand, 2001, p. 72-4.
[5] Rubber Authority of Thailand. Press Release March 2016. Available at: http://www.rubber.co.th/ewt_news.php?nid=2657&filename=index, accessed March 2016.
[6] RRIT. *Recommended Clone in 1999*. Rubber Research Institute, Department of Agriculture, Ministry of Agriculture and Cooperative, Thailand, 1999.
[7] VM Shorrocks. *Mineral Deficiencies in Hevea and Associated Cover Plants*. Rubber Research Institute of Malaya, Kuala Lumpur, 1964, p. 25-32.
[8] Malaysian Rubber Board. *Rubber Plantation and Processing Technology*. 1st ed. Malaysian Rubber Board, Kuala Lampur, 2009.
[9] WD Noordin. *Rubber Plantation: Soil Management and Nutritional Requirement*. Serdang, UPM, Salangor, Malaysia, 2011.
[10] AU Akpan, SO Edem and NU Ndaeyo. Latex yield of rubber (*Hevea brasiliensis* Muell Argo) as influenced by clone planted and locations with varying fertility status. *J. Agric. Soc. Sci.* 2007; **3**, 28-30.
[11] Y Waizah, FO Uzu, JR Orimoloye and SO Idoko. Effects of rubber effluent, urea and rock phosphate on soil properties and rubber seedlings in acid sandy soil. *Afr. J. Agric. Res.* 2011; **6**, 3733-9.
[12] P Timkhum, S Maneepong, M Issarakrisila and K Sangsing. Nutrient assessment with omission pot trials for management of rubber growing Soil. *J. Agri. Sci.* 2013; **5**, 10-9.
[13] M Karthikakuttyamma, M Joseph and ANS Nair. *Soil and Nutrition. In*: PJ George and CK Jacob (eds.). Natural Rubber: Agromanagement and Crop Processing. Rubber Research Institute of India, Kottayam, India, 2000, p. 170-98.
[14] S Thitithanakul, G Pételt, M Chalot and F Beaujard. Supplying nitrate before bud break induces pronounced changes in nitrogen nutrition and growth of young poplars. *Funct. Plant Biol.* 2012; **39**, 795-803.
[15] M Delaire, JC Mauget and F Beaujard. Evidence for a strong correlation between season-dependent nitrate and potassium uptake in two deciduous trees. *Trees* 2014; **28**, 769-76.
[16] F Beaujard and G Hunault. An original approach to study the kinetics of mineral element uptake for some woody species. *Acta Hortic.* 1996; **435**, 243-53.
[17] B Hirel, JL Gouis, B Ney and A Gallais. The challenge of improving nitrogen use efficiency in crop plants: Towards a more central role for genetic variability and quantitative genetics within integrated approaches. *J. Exp. Bot.* 2007, **58**, 2369-87.

[18] R Clark. Nutrient solution growth of sorghum and corn in mineral nutrition studies. *J. Plant Nutr.* 1982; **5**, 1039-57.
[19] LR Terry. Improving nutrient efficiency. *Turk. J. Agric. For.* 2008; **32**, 177-82.
[20] LI Trejo-Téllez and FC Gómez-Merino. *Nutrient Solution for Hydroponic Systems. In*: T Asao (ed.). Hydroponics - A Standard Methodology for Plant Biological Researches. InTech, Croatia, 2012, p. 1-22.
[21] DP Schachtman, RJ Reid and SM Ayling. Phosphorus uptake by plants: from soil to cell. *Plant Physiol*. 1998; **116**, 447-53.
[22] P Pongwichian, AC Clermont-Dauphin, BC Dissataporn and AN Suvannang. A qualitative assessment of the N status of young rubber trees as affected by interrank crops in northeast Thailand. *In*: Proceedings of the 19^{th} World Congress of Soil Science, Soil Solutions for a Changing World, Brisbane, Australia, 2010, p. 10-3.
[23] RRIT. *Natural Rubber Technical Information*. Rubber Research Institute, Department of Agriculture, Ministry of Agriculture and Cooperative, Thailand, 2011.
[24] SJ Mokhatar and NW Daud. Performance of *Hevea Brasiliensis* on haplic acrisol soil as affected by difference source of fertilizer. *Int. J. Appl. Sci. Tech.* 2011; **1**, 50-3.
[25] Office of Agricultural Economics. Monthly Retail Prices of Chemical Fertilizer 2015 - 2016. Available at: http://www.oae.go.th/ewt_news.php?nid=147&filename=index, accessed December 2016.
[26] M Arkoun, X Sarda, L Jannin, P Laîné, P Etienne, JM Garcia-Mina, JC Yvin and A Ourry. Hydroponics versus field lysimeter studies of urea, ammonium and nitrate uptake by oilseed rape (*Brassica napus* L.) *J. Exp. Bot*. 2012; **63**, 5245-58.
[27] XW Tan, H Ikeda and M Oda. The absorption, translocation, and assimilation of urea, nitrate or ammonium in tomato plants at different plant growth stages in hydroponic culture. *Sci. Hortic*. 2000; **84**, 275-83.
[28] B Bar-Yosef, NS Mattson and HJ Lieth. Effects of NH_4:NO_3: Urea ratio on cut roses yield, leaf nutrients content and proton efflux by roots in closed hydroponic system. *Sci. Hortic*. 2009; **122**, 610-9.