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Research Article

Cations-Base Application in Rubber Plantation: The Change of Calcium, Magnesium, and Potassium Status in the Soil and Leaves and Its Relation to Latex Yield

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Ultisols

Abstract: Nutrient balance in the soil support plant growth and yield. The objective of this study was aimed to obtain doses of calcium, magnesium, and potassium fertilizers in relation to the ratio of cations-base (Ca^{2+}, Mg^{2+}, K^{+}) to increase latex yield in rubber plants. The study was conducted on a rubber plantation in Dolok Masihul Sub-district, Serdang Bedagai District, North Sumatra, Indonesia, from January to August 2019. The treatment was used with three factors, including the first factor was $CaCO_3$ (0; 1 500 g/tree/year), the second factor of $MgSO_4.H_2O$ (0; 1 500; 3 000; 4 500 g/tree/year), and the third factor by KCl (0; 500; 1 000; 1 500 g/tree/year) in a Randomized Block Design (RBD) within three replicates. Results showed that the calcium of 1 500 g/tree/year increased the Mg-latex and latex yield by 160.70 g/tree/*tapping*. An increase in the three cations-base in soil, leaves, latex, and latex yield was also observed after the application of magnesium ranged by 1 500 to 4 500 g/tree/year. The potassium 500 - 1 500 g/tree/year increased the cations-base in soil, latex, and Ca-leaves. The interaction of calcium 1 500 + magnesium 1 500 - 4 500 and potassium 0-1 500 g/tree/year increased the *exchange-K*, Mg-latex, and also Mg- and K-leaves. The ratio of Ca:Mg:K in soil, leaves, and latex were 2: 1: 2 (optimum), 5: 1: 11 (high), and 1: 11: 32. The Ca, Mg, K in leaves and K-latex positively correlates and increases latex yield due to the three fertilizations.

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1. Introduction

Rubber plantations (*Hevea brasiliensis* Muell. Arg.) are the main commercial source of natural rubber (NR), an important raw material in several sectors, one of which is the tire industry (Vaysse et al., 2012). The area of rubber plantations worldwide is approximately 11.5 million ha, of which 90% was found in Southeast Asia countries, including Thailand, Indonesia, Malaysia, Vietnam, and India (Food and Agriculture Organization of the United Nations, 2016). However, most government-rubber plantations in Indonesia are still monoculture. Meanwhile, the management of nutrients such as N, P, K, Ca, and Mg in monoculture rubber is a factor that influences growth and yield (Vrignon-Brenas et al., 2019). Thitithanakul et al. (2017) reported that the total nitrogen and total-P requirement of the clone RRIM600 rubber were 1191.08 and 112.52 mg/plant, while the clone RRIT251 required total-N and total-P were 1241.09 and 131.81 mg/plant, respectively. Moreover, Mokhatar et al. (2012) stated that N-P-K-Mg fertilization with a ratio of 10.7; 16.6; 9.5; 2.4 at 150% in the recommended dose or 28.13 kg ha^{-1} significantly increased the highest nutrient content of N, K, and Mg in the RRIM2001 clone rubber were 54.17; 61.90; and 92.86%, respectively compared to the control. Suchartgul et al. (2011) reported that the standard optimum requirements for macronutrients including N, P, K, Ca, and Mg in the leaves of clone RRIM600 rubber were 3.20; 0.25; 1; 1; >0.35%, respectively. Additionally, Correia et al. (2017) also reported that K_2O fertilization at a dose of 0.2 kg m^{-3} increased the total dry weight by 141.72 g/plant in the GT1 clone rubber.

The status and balance of nutrient in the soil considerably affect plant growth and yield (Öborn et al., 2003). However, certain nutrients have synergistic or antagonistic properties between ions. Voogt (1987) stated that the uptake of K, Ca, and Mg depends not only on the soil concentration but also on the content ratio; hence when one of the nutrients is in excess, this might lead to a deficiency of others. Furthermore, Nguyen et al. (2015) reported that a high concentration of Mg in the soil inhibits the absorption of K and Ca. Weerasuriya and Yogaratnam (1989); Singh et al. (2005) added that there is a strong antagonism between K and Mg uptake in rubber plants.

The existence of synergism or antagonism between Ca, Mg, and K ions in the soil cause an imbalance among the nutrients absorbed by plants. Therefore, balanced nutrient management, especially for K, Ca, and Mg in rubber plantations based on soil, leaf, and latex analysis, is needed. Balanced fertilization is expected to be used as a guideline for nutrient management based on nutrient ratios of K/Mg, K/Ca, and Mg/Ca in the soil, leaves, and latex of rubber plants. Therefore, this study was aimed to obtain doses of calcium, magnesium, and potassium fertilizers in relation to the cations ratio of Ca, Mg, and K to increase latex yield in mature-4 of rubber plants.

2. Material and Methods

2.1. Study area

This study was conducted at the afdeling-II, Sarang Giting Estate, PTPN-III, Serdang Bedagai District, North Sumatra, Indonesia, from January to August 2019. Sarang Giting Estate was selected due to its high latex productivity of 1,853.24 kg ha^{-1} year^{-1} among other plantations with similar management of high metabolism clone RRIM712 aged 9 years and the ultisols soil type. Meanwhile, the sample plants were selected based on criteria for healthy plants with stem diameters ranging from 65 to 80 cm. References on the relationship between rubber stem diameter and nutrient uptake have not been reported, but Murbach et al. (2003) found that the nutrient uptake of K and Mg (73–86 and 27%) in rubber plants was higher in 13-years-old. Therefore, the selection of rubber plants in this study was based on plant age.

2.2. Initial soil analysis

Initial soil samples were collected using a soil drill with a depth of 0-30 cm in the weeding circle with a distance of 165-250 cm. A total of three samples were composited and analyzed in the analytical laboratory of PT. Socfin Indonesia (Table 1). Soil sampling depth was based on the findings of Song et al. (2022) that rubber plants absorb nutrients from a depth of 5–50 cm and then decrease as the depth increases.

Table 1. Initial soil characteristics of the study area

Soil characteristics	Method	Value	Classification*
Soil texture	Hydrometer	Sand= 31% Silt= 51% Clay= 18%	Silt loam
Total-N (%)	Khejdahl	0.15	Low
pH-H_2O	Electrometric	5.20	Acid
P_2O_5 (ppm)	Bray-II	40.80	Very high
Total-P (%)	Bray-II	0.035	Very low
CEC (me/100 g)	NH_4OAc (pH 7)	6.77	Low
Exchangeable-K (me/100 g)	NH_4OAc (pH 7)	0.40	Moderate
Exchangeable-Ca (me/100 g)	NH_4OAc (pH 7)	0.32	Very low
Exchangeable-Mg (me/100 g)	NH_4OAc (pH 7)	0.32	Very low
Exchangeable-Al (me/100 g)	KCl 1N	0.22	Very low

Note: *Soil Research Institute, (2009) with the criteria of total-N was low (0.1-0.2); pH 4.5-5.5 (acid); P_2O_5 >15 ppm (very high); total-P <5% (very low); cation exchange capacity (CEC) 5-16 me/100 g (low); exchangeable-K 0.4-0.5 me/100 g (moderate); exchangeable-Ca <2 me/100 g (very low); exchangeable-Mg <0.40 me/100 g (very low); exchangeable-Al <5 me/100 g (very low).

2.3. Study design

In this study, conversion dose requirements and a Randomized Block Design (RBD) with three factors were used. The first factor was calcium from calcium carbonate fertilizer ($CaCO_3$) at the rates of 0 (C_0) and 1 500 g/tree/year (C1). The second factor was magnesium from kieserite fertilizer ($MgSO_4.H_2O$) at the levels of 0 (M_0), 1 500 (M_1), 3 000 (M_2), and 4 500 g/tree/year (M_3). The third factor was potassium from KCl fertilizer at the rates of 0 (K_0), 500 (K_1), 1 000 (K_2), and 1 500 g/tree/year (K_3). All treatments were conducted by three replications. The rubber plants were fertilized by making an oval-row placement array 5 cm deep and then covered with soil. Fertilization was performed every two months alternately, with the first application at a distance of 2.5×1.65 m (zone-A) and the second at a distance of 5×3.3 m (zone-B) from the plant (Figure 1). The requirement for Mg and K fertilizers was based on the initial soil analysis shown in Table 1, while the Ca fertilizers are based on 1.5 times from exchangeable-Al. Furthermore, the results were converted to determine the dose of fertilizer/ha.

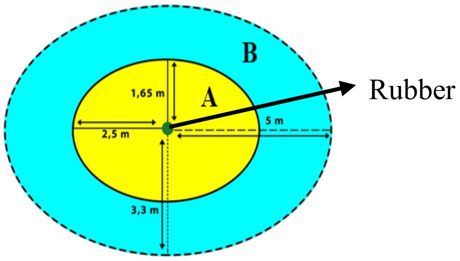

Figure 1. Fertilization design on rubber plants in the study area. The first (A) and the second (B) application zones.

2.4. Parameters and data analysis

The parameters in this study, including soil, plant tissue (leaves and latex), latex yield, cations-base ratio, and correlation analysis, were measured at eight Months After Fertilization (MAF). The soil samples were collected using a drill at a depth of 0-30 cm in the weeding circle area, while a total of three samples were composited. Afterward, soil exchangeable (Ca, Mg, K) were analyzed using the ammonium acetate saturation method pH 7. The leaves and latex sampling was implemented at 10.00-11.00 AM with 30 and 10 g samples, respectively. The leaves samples were initially soaked in 70% alcohol for several minutes and then dried, while the latex was only dried. Furthermore, the nutrient content of Ca, Mg, and K in the leaves and latex samples were analyzed using the ammonium acetate saturation method pH 7.

The latex yield was conducted by tapping every four days, followed by weighing the fresh latex in g/tree/tapping. Meanwhile, parameters of nutrient ratio for Ca, Mg, and K with latex yield were measured for the interaction of the three fertilizations with the highest latex yield. The ratios of K/Mg, K/Ca, and Mg/Ca in the soil and leaves were classified according to Suchartgul et al. (2011). The soil and leaves were consisted of low category ratios of K/Mg, K/Ca, and Mg/Ca (<2; <0.4; <0.2 and <3;

<0.8; <0.3), the optimum classified (2-6; 0.4-1.4; 0.2- 0.6; and 3.0-4.2; 0.8-1, 4; 0.3-0.5), and the high classified (>6; >1.4; >0.6 and >4.2; >1.4; >0.5). Data on the content of Ca, Mg, and K in soil, leaves, latex, and latex yield were analyzed using ANOVA, while the significance was further examined using the DMRT at $P<0.05$. Additionally, all data in natural logarithm and Pearson correlation analysis was performed using IBM SPSS v.20 software to obtain the relationship between the cations-base in soil, leaves, and latex on the latex yield.

3. Results

3.1. Cations-base (Ca, K, Mg) in soil

Fertilization with magnesium, potassium, and the third interaction of fertilizers significantly increased cations-base (Ca, Mg, K) in the soil, as shown in Tables 2 and 3. However, calcium fertilization was less effective in increasing soil cations at the 8 MAF. This is demonstrated in the control treatment, which provided higher soil exchangeable (Ca and Mg) compared to a dose of 1 500 g/tree/year. A similar result was also observed in the untreated magnesium fertilizer which had higher the exchangeable-Ca. Meanwhile, magnesium fertilization at doses of 4 500 and 1 500 g/tree/year increased soil exchangeable (Mg and K) by 20.41% and 1.33%, respectively, compared to the control.

Potassium fertilization with a dose of 1 500 g/tree/year showed the highest increase in the cations-base (Ca, Mg, K) in the soil at 9.72, 45.45, and 68.00% compared to the control. Meanwhile, the interaction of 0 g Ca+4 500 g Mg+1 500 g K and 1 500 g Ca+1 500 g Mg+1 500 g K produced the highest increase in the cations-base (Mg, K) in soil by 77.42 and 221.43%. However, the combined interaction was less effective in increasing the exchangeable-Ca in soil.

Table 2. Effect of calcium, magnesium, and potassium fertilization on cations-base in soil, nutrient content (in leaves and latex), and latex yield of mature-4 in rubber plants at the 8 Months After Fertilization (MAF)

Fertilization doses (g/tree/year)	Cations-base in soil (me/100 g)			Nutrient content in leaves (%)			Nutrient content in latex (%)			Latex yield (g/tree/tapping)
	Exch-Ca	Exch-Mg	Exch-K	Ca	Mg	K	Ca	Mg	K	
Calcium (Ca)										
0	0.76a	0.56a	0.73ns	0.93a	0.27ns	2.12ns	0.017a	0.08b	0.37ns	142.08b
1 500	0.71b	0.47b	0.71ns	0.87b	0.28ns	2.11ns	0.015b	0.10a	0.38ns	160.70a
Magnesium(Mg)										
0	0.79a	0.49b	0.75ab	0.96a	0.28ns	2.07ab	0.017a	0.09b	0.42a	138.88b
1 500	0.67c	0.45c	0.76a	0.91ab	0.28ns	2.20a	0.016a	0.08bc	0.39ab	158.70a
3 000	0.78a	0.52b	0.72b	0.85c	0.28ns	2.17a	0.013c	0.07c	0.32c	169.70a
4 500	0.70b	0.59a	0.65c	0.88bc	0.26ns	2.02b	0.019a	0.11a	0.38b	138.28b
Potassium (K)										
0	0.72b	0.44c	0.50d	0.93ab	0.28ns	2.14ns	0.016bc	0.10a	0.38b	148.51ns
500	0.70b	0.50b	0.74c	0.96a	0.27ns	2.10ns	0.016b	0.09a	0.36b	148.63ns
1 000	0.73b	0.47bc	0.80b	0.87bc	0.28ns	2.06ns	0.019a	0.08b	0.36b	152.81ns
1 500	0.79a	0.64a	0.84a	0.85c	0.27ns	2.15ns	0.014c	0.09a	0.42a	155.62ns

Note: the values followed by the same letter in the same column are not significantly different at the 5% level based on the DMRT. ns= not significant.

3.2. Nutrients content (Ca, Mg, K) in leaves

Fertilization with calcium and potassium only significantly increased the nutrients content of Ca, but it was insignificantly for Mg and K in the leaves. Meanwhile, magnesium fertilization significantly increased the nutrients content of Ca and K, but it was insignificantly for Mg-leaves. Moreover, the third interaction of fertilizers significantly increased the nutrients content for Ca, Mg, and K-leaves after 8 MAF is presented in Tables 2 and 3. The results also showed that calcium fertilization was less effective in increasing Ca-leaves. This is seen in the untreated calcium fertilizer which produced higher Ca levels compared to a dose of 1 500 g/tree/year.

A similar result was also observed in the untreated of magnesium fertilization which had higher Ca levels compared to another dose. Magnesium fertilization at a dose of 1 500 g/tree/year showed the highest increase of K-leaves by 6.28%, while potassium with a dose of 500 g/tree/year caused the highest in Ca levels by 3.23%. Furthermore, the interaction of 0 g Ca+4 500 g Mg+1 000 g K showed the highest increase of Ca-leaves by 34.51%. Likewise, the interaction of 1 500 g Ca+1 500 g Mg+1 000 g K increased the highest of Mg and K-leaves by 93.75 and 30.19%, respectively.

Table 3. Effect of the third interaction of fertilization on cations-base in soil, nutrient content (in leaves and latex), and latex yield of mature-4 in rubber plants at the 8 Months After Fertilization (MAF)

Interaction (C×Mg×K)	Cations-base in soil (me/100 g)			Nutrient content in leaves (%)			Nutrient content in latex (%)			Latex yield (g/tree/tapping)
	Exch-Ca	Exch-Mg	Exch-K	Ca	Mg	K	Ca	Mg	K	
$C_0M_0K_0$	1.16a	0.62cd	0.42i	1.13bcd	0.32cd	2.12b-h	0.010j-p	0.13b-e	0.31h-j	109.83ns
$C_0M_0K_1$	0.56k-n	0.42fgh	0.76a-i	1.06b-e	0.30c-e	2.30a-f	0.018e-h	0.07g-k	0.35f-j	133.61ns
$C_0M_0K_2$	0.58k-n	0.41f-i	0.69a-i	0.92d-h	0.24e-k	2.18b-g	0.013i-p	0.06h-k	0.44c-g	115.39ns
$C_0M_0K_3$	0.61j-m	0.37ghi	0.82a-i	0.64i-l	0.28c-g	2.44a-d	0.014h-n	0.04j-k	0.49a-e	149.89ns
$C_0M_1K_0$	0.61j-m	0.38f-i	0.49ghi	0.88e-h	0.24d-k	1.88f-j	0.030b	0.09e-h	0.35f-j	148.22ns
$C_0M_1K_1$	0.79d-g	0.44fgh	0.79a-i	1.28ab	0.24d-k	2.13b-h	0.009p	0.06g-k	0.32g-j	114.06ns
$C_0M_1K_2$	0.49no	0.29i	0.71a-i	0.92d-h	0.19j-k	2.09b-i	0.021cde	0.06h-k	0.44c-g	151.83ns
$C_0M_1K_3$	0.85cd	1.01a	0.96a-e	0.82e-j	0.24d-k	1.92e-j	0.021def	0.16bc	0.58ab	149.44ns
$C_0M_2K_0$	0.71ghi	0.51def	0.62b-i	0.93d-h	0.30c-f	2.27b-f	0.011j-p	0.06g-k	0.37e-j	140.50ns
$C_0M_2K_1$	0.90bc	0.64cd	0.54c-i	0.95d-h	0.27c-i	2.50ab	0.014h-l	0.03k	0.18k	150.00ns
$C_0M_2K_2$	0.78d-g	0.58cde	1.29ab	0.56k-l	0.22f-k	2.12b-h	0.019efg	0.04i-k	0.16k	156.67ns
$C_0M_2K_3$	0.89bc	0.76b	0.86a-f	0.91d-h	0.52b	2.18b-g	0.014h-o	0.09e-h	0.27i-k	156.50ns
$C_0M_3K_0$	0.55lmn	0.36ghi	0.43i	0.59j-l	0.24d-k	2.03d-j	0.012i-p	0.04j-k	0.27i-k	154.67ns
$C_0M_3K_1$	0.45o	0.41f-1	0.45hi	0.77h-k	0.30c-f	2.04c-j	0.015g-k	0.09e-i	0.46b-f	129.61ns
$C_0M_3K_2$	1.09a	0.62cd	1.16a-d	1.52a	0.24e-k	1.64i-j	0.035a	0.16bc	0.36f-j	157.94ns
$C_0M_3K_3$	1.10a	1.10a	0.65b-i	1.03b-g	0.19k	2.03c-j	0.009p	0.10d-g	0.59a	155.17ns
$C_1M_0K_0$	0.84cde	0.49efg	0.58c-i	0.90d-h	0.28c-h	2.07b-i	0.024cd	0.08f-j	0.42c-h	137.44ns
$C_1M_0K_1$	0.96b	0.65bc	1.27abc	0.79g-k	0.22g-k	1.76g-j	0.026bc	0.17b	0.53abc	129.94ns
$C_1M_0K_2$	0.75e-h	0.38ghi	0.61b-i	1.21bc	0.28c-g	1.75g-j	0.015g-j	0.04i-k	0.37d-i	186.22ns
$C_1M_0K_3$	0.85cd	0.59cde	0.85a-g	1.05b-f	0.32cd	1.94e-j	0.011j-p	0.14bcd	0.40d-i	148.72ns
$C_1M_1K_0$	0.56k-n	0.37ghi	0.43i	1.05b-f	0.19j-k	2.08b-i	0.011j-p	0.07g-k	0.47a-f	172.50ns
$C_1M_1K_1$	0.68hij	0.40f-i	0.65b-i	1.03c-g	0.30c-e	2.24b-f	0.012i-p	0.04j-k	0.28i-j	183.00ns
$C_1M_1K_2$	0.73f-i	0.42fgh	0.67b-i	0.81f-j	0.62a	2.76a	0.012i-p	0.12c-f	0.50a-d	173.22ns
$C_1M_1K_3$	0.64i-l	0.31h	1.35a	0.50i	0.22f-k	2.53ab	0.013i-p	0.03k	0.19k	177.33ns
$C_1M_2K_0$	0.78d-g	0.45fg	0.56c-i	1.04b-g	0.32cd	2.20b-g	0.005p	0.05h-k	0.42c-h	174.44ns
$C_1M_2K_1$	0.74fgh	0.42fgh	0.77a-i	0.95d-h	0.20i-k	2.15b-h	0.014h-m	0.15bc	0.45b-g	215.00ns
$C_1M_2K_2$	0.81c-f	0.40f-i	0.58c-i	0.44l	0.19j-k	1.62j	0.011j-p	0.06g-k	0.28i-k	172.61ns
$C_1M_2K_3$	0.64ijk	0.38f-i	0.53ghi	0.99c-h	0.20h-k	2.31a-f	0.012i-p	0.08g-j	0.47a-f	191.89ns
$C_1M_3K_0$	0.54mn	0.36ghi	0.45hi	0.89d-h	0.34c	2.49abc	0.021def	0.24a	0.40d-i	150.44ns
$C_1M_3K_1$	0.54mn	0.65bc	0.67a-i	0.83e-j	0.30cde	1.71h-j	0.016f-i	0.12c-f	0.27j-k	133.78ns
$C_1M_3K_2$	0.61j-m	0.64cd	0.65b-i	0.57k-l	0.27c-j	2.34a-e	0.021cde	0.06g-k	0.28i-k	108.61ns
$C_1M_3K_3$	0.74fgh	0.59cde	0.70a-i	0.84e-i	0.21g-k	1.86f-j	0.019efg	0.08f-j	0.38d-i	116.00ns

Note: the values followed by the same letter in the same column are not significantly different at the 5% level based on the DMRT. ns= not significant. Calcium fertilization (C_0= 0; C_1= 1 500 g/tree/year); magnesium fertilization (M_0= 0; M_1= 1 500; M_2= 3 000; M_3= 4 500 g/tree/year); and potassium fertilization (K_0= 0; K_1= 500; K_2= 1 000; K_3= 1 500 g/tree/year).

3.3. Nutrients content (Ca, Mg, K) in latex

Fertilization with magnesium, potassium and the third interaction of fertilizers significantly increased the nutrients content of Ca, Mg, and K in the latex of mature-4 rubber plant at 8 MAF. Meanwhile, calcium fertilization significantly increased the nutrients content of Ca and Mg, but it was insignificantly of K-latex (Tables 2 and 3). The results showed that calcium fertilization was less effective in increasing Ca levels in latex. This is indicated in the untreated calcium fertilization which produced higher Ca levels, but a dose of 1 500 g/tree/year significantly increased Mg-latex by 25.00% compared to the control. A similar result was also observed in the control, which had higher K levels compared to another of magnesium. However, a dose of 4 500 g/tree/year produced the highest increase in Ca and Mg of 11.76 and 22.22%, respectively. Meanwhile, potassium fertilization at doses of 1 000 and 1 500 g/tree/year showed the highest increase in Ca and K levels of 18.75 and 10.53%, respectively, but it was less effective in increasing Mg-latex. The interaction of 0 g Ca+4 500 g Mg+1 000 to 1 500 g K and 1 500 g Ca+4 500 g Mg+0 g K showed the highest increase in Mg and K levels were 3.5 times; 90.32% and 84.62%, respectively.

3.4. Latex yield

Calcium and magnesium fertilization significantly increased latex yield, but potassium and the third interaction of fertilizers were insignificantly on the latex yield of mature-4 rubber plants (Tables 2 and 3). Fertilization of calcium at 1 500 g and magnesium at 3 000 g showed the highest latex yield of 13.11 and 22.19%, respectively, compared to the control. Although potassium had an insignificant effect, there was an increase in latex yield along with an increase in the doses of potassium fertilizer until 1 500 g/tree/year. Likewise, the highest latex yield was obtained with an interaction of 1 500 g Ca+3 000 g Mg+500 g K by 95.76% compared to the control.

3.5. Nutrients ratio

The nutrients ratio of Ca, Mg, and K in rubber plants with the highest latex yield were obtained from the interaction of calcium 1 500 g+magnesium 3 000 g+potassium 500 g as shown in Table 4. Based on the results, the nutrient ratios of Ca:Mg:K in soil, leaves and latex due to the three fertilizations were 2: 1: 2; 5: 1: 11; and 1: 11: 32, respectively. The ratio of K/Mg, and K/Ca was classified as optimum in the soil and high in the leaves, but Mg/Ca ratio was classified as low. These three ratios indicate that the optimal nutrient ratio in the soil support nutrient uptake both to the leaves and latex of the rubber plants. Moreover, the nutrients uptake of K and Mg tends to be abundant in latex compared to the leaves, while Ca was higher in the leaves.

Table 4. Nutrient ratios of Ca, Mg, and K in rubber plants with the highest latex yield at the interaction of calcium (1 500 g)+magnesium (3 000 g)+potassium (500 g)

Analysis	Nutrient content			Nutrient ratios					
	Ca	Mg	K	Ca/K	Ca/Mg	Mg/K	K/Mg	K/Ca	Mg/Ca
Soil (me/100 g)	0.74 (2)	0.42 (1)	0.74 (2)	1.00	2.00	0.50	2.00	1.00	0.50
Leaves (%)	0.95 (5)	0.20 (1)	2.15 (11)	0.45	5.00	0.09	11.00	2.20	0.20
Latex (%)	0.014 (1)	0.15 (11)	0.45 (32)	0.03	0.09	0.34	2.91	32.00	11.00

3.6. Correlation analysis

Correlation analysis between nutrients content of Ca, Mg, and K in soil, leaves, and latex on the latex yield are shown in Table 5.

Table 5. Correlation analysis between nutrients content of Ca, Mg, K in soil, leaves, and latex on the latex yield of mature-4 rubber plant

Correlation analysis	Ca	Mg	K	Latex yield
Soil				
Ca	1			
Mg	0.635**	1		
K	0.318**	0.263**	1	
Latex yield	0.053	-0.180	0.106	1
Leaves				
Ca	1			
Mg	0.262**	1		
K	0.108	0.414**	1	
Latex yield	0.225*	0.232*	0.324**	1
Latex				
Ca	1			
Mg	0.364**	1		
K	0.080	0.584**	1	
Latex yield	0.008	0.184	0.271**	1

Note: ** and *Correlation is significant at the 0.01 and 0.05 level (2-tailed). n= 96.

Nutrients content of Ca and K in soil positively correlated, while Mg negatively correlated to latex yield. In the leaves, the Ca, Mg, and K nutrients were significantly and positively correlated on the latex yield. Furthermore, K nutrient contributed higher in latex yield compared to Ca and Mg nutrients.

The K nutrient in the latex was significantly and positively correlated in latex yield, while Ca and Mg nutrients in latex were positively correlated, but it was an insignificant effect.

4. Discussion

4.1. Effect of calcium fertilization

Calcium fertilization statistically affected cations-base (Ca and Mg) in soil, Ca-leaves, Ca and Mg-latex, and also the latex yield (Tables 2 and 3). It also had a slight effect in increasing cations-base (Ca and Mg) in the soil, and Ca in leaves and latex of mature-4 rubber plants at 8 MAF. The calcium fertilization had a weak effect on latex yield indicated by a higher yield found in the untreated compared to a dose of 1 500 g/tree/year. The use of 1 500 g/tree/year increased Mg in latex and the yield by 25.00 and 13.11%, respectively. This is due to the K^+ ion, which has a lower valence electron and is highly absorbed compared to the Mg^{2+} and Ca^{2+} ions, even though calcium fertilization is applied. This result is linear with Ca nutrient, which had a positive correlation and highly significant (0.364**) to Mg in latex, and it had a positive correlation (0.008) for the latex yield (Table 5).

A similar result was reported by White (2001) that the cations uptake, such as Mg^{2+} and K^+, competed with Ca^{2+} in plant roots. Mengel et al. (2001) added that potassium ions are more efficiently absorbed than Ca or Mg due to the effectiveness of the H^+/K^+ symport enzyme, namely a protein that transports H^+ and K^+ simultaneously across the root cell membrane. Furthermore, White and Broadley (2003) reported that Ca activates various metabolisms in plant tissues, such as cell growth, cytoplasmic flow, mitosis, cytokinesis, and activator of enzymes associated with Ca-binding proteins. This calcium mechanism causes latex yield to increase by 13.11% (Table 4). Zhu et al. (2018) stated that calcium-dependent protein kinases play a key role in tissue interactions. This indicates that protein kinase and protein phosphorylation are important in ethylene signaling in rubber latex. Wang et al. (2015) also reported that the level of protein phosphorylation and expression of calcium-binding protein kinase in latex increased significantly after ethylene stimulation.

4.2. Effect of magnesium fertilization

Magnesium fertilization statistically affected the cations-base (Ca, Mg, K) in soil, the nutrients content of Ca and K in leaves, nutrients content of Ca, Mg, K in latex, and the latex yield of mature-4 rubber plants (Tables 2 and 3). Its application at a dose of 0 g/tree/year produced higher exchangeable-Ca in soil, Ca-leaves, and K-latex compared to other doses of magnesium, but at the dose of 1 500 g/tree/year increased exchangeable-K in soil and K-leaves by 1.33 and 6.28%, respectively. Similarly, magnesium at a dose of 4 500 g/tree/year increased the exchangeable-Mg, Ca, and Mg-latex by 20.41; 11.76; and 22.22%, respectively. Furthermore, the highest increase in latex yield of 22.19% was produced with a dose of 3 000 g/tree/year. Magnesium fertilization at a dose of 1 500 to 4 500 g/tree/year increased cations-base in soil, nutrients content in leaves and latex, as well as the latex yield of rubber plants. This indicates that there is a synergy between Mg and K nutrients in certain metabolic processes of plants.

These results are linear with Mg nutrients which had a positive correlation and highly significant with K in soil, leaves, and latex were 0.263**; 0.414**; and 0.584**; respectively, and Ca-latex of 0.364**. A similar content of Mg-leaves and latex correlated positively (0.232* and 0.184) on the latex yield (Table 5). According to Guo et al. (2010), Mg had a synergistic effect on potassium transport to the plant shoots, photosynthetic electron transport, photoassimilate formation, sucrose filling in the phloem, and nitrogen metabolism. Moreover, Karley and White (2009) added that K^+ and Mg^{2+} had different roles during transport in the xylem and phloem tissues, although both are highly mobile cations. Meanwhile, Tromp and van Vuure (1993) reported that Mg^{2+} is more easily absorbed by parenchymal cells than K^+ due to its higher valency. An unbalanced K/Mg ratio resulted in a higher concentration and transport rate of K^+ than Mg^{2+}. Based on the results, the ratio of K/Mg in soil, leaves, and latex were 2; 11; and 2.91, respectively (Table 4), which indicates that the concentration of K was higher compared to Mg. It has been reported by Hytönen et al. (2019) that the Mg content is higher in leaves and branches in a size less than 3 mm in rubber plants of 3.5 and 2.7 g kg^{-1}, respectively. Murbach et al. (2003) also added that Mg in latex of 13-year-old rubber plants was 0.4 kg ha^{-1} in Brazil.

4.3. Effect of potassium fertilization

Potassium fertilization statistically affected cations-base (Ca, Mg, K) in soil, Ca nutrient in leaves, and nutrients content (Ca, Mg, K) in latex, but it was insignificant to the latex yield of mature-4 rubber plant at 8 MAF (Tables 2 and 3). The dose of 500 g/tree/year produced the highest Ca of 3.23% in leaves, while the dose of 1 000 g/tree/year increased the highest Ca of 18.75% in latex compared to the control. Furthermore, potassium increased the highest cations-base (Ca, Mg, K) in soil and K-latex at 9.72, 45.45, 68.00, and 10.53%, respectively, but it was less effective in increasing Mg nutrient in latex. In general, potassium fertilization at a dose of 500 - 1 500 g/tree/year increased soil cations-base, nutrients in leaves and latex, but it was an insignificant effect on the latex yield of rubber plants. This is linear with the nutrient ratio of K/Ca in leaves and latex by 2.20 and 32, while K/Mg was 11 and 2.91, respectively (Table 4).

This indicates that the content of K nutrients in the leaves and latex tissue are more highly absorbed than Ca and Mg. Also, this finding authenticates that nutrient K had an insignificant effect on Ca-leaves by 0.108 and latex by 0.080. In contrast, K had a positive correlation and significance on the cations-base (Ca and Mg) in the soil of 0.318** and 0.263**, respectively (Table 5). This result is supported by Rhodes et al. (2018) ,who stated that potassium fertilization up to 300 kg ha^{-1} significantly increased the K concentration in the leaves, but an increase in the K concentration causes a decrease in Ca and Mg in the leaves. Fageria (1983) reported that a low concentration of K^{+} stimulates Mg^{2+} absorption and vice versa. Furthermore, Xie et al. (2021) also reported that the antagonistic effect of K to Mg is stronger compared to Mg with K in root absorption and transport. Therefore, K and Mg fertilization must be balanced to reduce Mg deficiency. Amiri et al. (2022) added that potassium fertilization was highly significant for grain yield and harvest index of *Cyamopsis tetragonoloba*. Abu-Alama et al. (2022) also found potassium fertilizer dose of 80 kg/ha significantly increased the highest sugarcane yield by 9.93% compared to control.

4.4. Interaction of calcium, magnesium, and potassium fertilization

The interaction of Ca×Mg×K fertilization significantly increased the cations-base in soil, nutrient content (Ca, Mg, K) in leaves and latex, but it was insignificant to latex yield of mature-4 rubber plant at 8 MAF (Tables 2 and 3). The interaction of 0 g Ca+4 500 g Mg+1 000 g K increased the highest of Ca-leaves and latex by 34.51% and 3.5 times, while the interaction of 0 g Ca+4 500 g Mg+1 500 g K increased the Mg cation in soil and K-latex of 77.42 and 90.32%, respectively. In general, the combination untreated of calcium fertilizer+magnesium 4 500 g+potassium 1 000 to 1 500 g affected the cations-base in soil, nutrients content in leaves, and latex of mature-4 rubber plant. It was indicated that magnesium fertilization is synergistic with potassium, even untreated calcium fertilizer. This is demonstrated by the K/Mg, K/Ca, and Mg/Ca ratios in the soil of 2, 1, and 0.5 (classified as optimum), and this ratio can be seen in Tab 4. In addition, potassium was positively correlated and significantly with magnesium in the soil, leaves, and latex, but potassium was positively correlated and insignificant with calcium in leaves and latex (Table 5). These results are supported by Guo et al. (2010) that Mg nutrient synergizes with K-transport to the plant shoots, photosynthetic electron transport, photoassimilate formation, sucrose filling in the phloem, and nitrogen metabolism. Suchartgul et al. (2011) reported that the optimum range of K/Mg, K/Ca, and Mg/Ca ratios in the soil on rubber plants of RRIM-600 clones were 2-6; 0.4-1.4; and 0.2-0.6, respectively. Moreover, Mg content in leaves and exchangeable-K in soil increased the stem diameter of rubber plants were 43.14 and 35.78%, but the exchangeable-Ca in the soil only contributed by 6.04%.

The interaction of 1 500 g Ca+1 500 g Mg+1 500 g K and 1 500 g Ca+4 500 g Mg+0 g K increased the exchangeable-K and Mg content in latex by 221.43 and 84.62%, respectively. Moreover, the interaction of 1 500 g Ca+1 500 g Mg+1 000 g K increased the highest Mg and K content in the leaves by 93.75 and 30.19%. In general, the combination of calcium 1 500+magnesium 1 500 to 4 500+potassium 0 until 1 500 g/tree/year also affected the exchangeable-K in soil, Mg, and K-leaves, as well as Mg-latex of rubber plants. This is due to the nutrient ratio of K/Mg, K/Ca, and Mg/Ca in the soil were classified as optimum (2: 1: 0.5), while K/Mg and K/Ca ratios in the leaves were classified as high by 11: 2.2 (Table 4). It is supported by the positive correlation and significance between K and Mg content in soil, leaves, and latex, as well as the relationship between Mg and Ca (Table 5). According to Xie et al. (2021), the optimal ratio of K/Mg in soil and plant tissue is used to defend the nutrients and support physiology processes to increase the plant yield. Furthermore, Suchartgul et al. (2011) also reported that the nutrients of K and Ca in the leaves increase the stem diameter of rubber plant clones RRIM-600 by 48.88 and 46.68%, respectively.

Conclusion

Fertilization with calcium (Ca) at a dose of 1,500 g/tree/year increased the Mg-latex and the latex yield by 25.00 and 13.11%. Meanwhile, magnesium (Mg) fertilizer at the dose of 1 500 g/tree/year increased the exchangeable-K in soil and K-leaves by 1.33 and 6.28%. Likewise, the dose of 3 000 g/tree/year had the highest latex yield of 22.19%. The 4 500 g/tree/year dose also increased the exchangeable-Mg in soil, Ca, and Mg-latex by 20.41; 11.76; and 22.22%. Furthermore, potassium (K) fertilizer at a dose of 500 g/tree/year increased the highest Ca-leaves by 3.23%, and the dose of 1 000 g/tree/year increased the highest Ca-latex by 18.75%, as well as the dose by of 1 500 g/trees/year, increased the highest cations-base (Ca, Mg, K) in soil, and K-latex by 9.72; 45.45; 68.00; and 10.53%, respectively.

The interaction untreated of calcium fertilization+magnesium 4 500+potassium 1 000 to 1 500 g/tree/year increased the exchangeable-Mg in soil, Ca-leaves, Ca, and K-latex. Meanwhile, the interaction of calcium 1 500+magnesium 1 500 to 4 500+potassium 0 until 1 500 g/tree/year increased the exchangeable-K, Mg-latex, Mg, and K-leaves. The interaction of calcium 1 500+magnesium 3 000+potassium 500 g/tree/year had the highest latex yield of 95.76% compared to the control. The nutrient ratios of Ca:Mg:K in the soil, leaves and latex due to the combined fertilizations were 2: 1: 2 (optimum), 5: 1: 11 (high), and 1: 11: 32. The cations-base of Ca and K in soil, nutrients content (Ca, Mg, K) in leaves and latex had a positively correlated with latex yield due to the third fertilizations.

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