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Response of Rubber Tree Saplings to Dolomite and Kieserite Application and K:Mg Ratio

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ABSTRACT

This study aimed to examine the effect of the application of dolomite and kieserite on the growth and nutrient uptake of rubber tree saplings and the relationship between K:Mg ratios in soils and nutrient uptake. The experiment followed a completely randomized design with five replicates. Budded stumps of RRIM 600 rubber were planted in soil with low extractable Mg (< 0.30 $cmol_c\ kg^{-1}$). Kieserite application at a rate of 0.5 $cmol_c$ Mg kg^{-1} significantly promoted the greatest sapling height, stem diameter, Mg and S concentrations, and leaf chlorophyll levels. High kieserite application rates (1.0 $cmol_c$ Mg kg^{-1}) were more likely to decrease K and N uptake significantly. Applying dolomite (0.5 $cmol_c$ Mg kg^{-1}) also significantly increased rubber growth compared with the control treatment but the significant increases were lower than those for kieserite application. Applying K at 72, 108, and 180 mg kg^{-1} significantly increased leaf K concentration, but significantly decreased Mg concentrations. Therefore, rubber plantations should apply Mg at a rate of 0.5 $cmol_c$ Mg kg^{-1} in the form of kieserite, and a ratio of K:Mg 2:1 is suitable for promoting rubber tree growth.

Keywords: Dolomite, K:Mg ratio, kieserite, plant nutrition, rubber tree sapling

INTRODUCTION

Para rubber is an important economic crop in Thailand. Fertiliser is a key factor in the success of rubber tree plantations. In the past, mixed chemical fertilisers that contained nitrogen (N), phosphorus (P), potassium (K), and magnesium (Mg) were recommended in Thailand (Rubber Research Institute of Malaya, 1963). After 1978, Mg

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was removed from the mixed chemical fertilisers used because the amount of Mg available in the soil was sufficient (Nualsri et al., 1982). Mixed chemical fertiliser 20-8-20 or 29-5-18 (N, P_2O_5, K_2O, respectively) was recommended for immature and mature rubber trees grown in traditional rubber cultivation areas (Rubber Research Institute of Thailand, 2019). In tropical soils that experience high weathering and soil leaching are low in basic cation (K^+, Na^+, Ca^{2+}, and Mg^{2+}) content (Brady & Weil, 2008). Therefore, intensive rubber cultivation up to the second or third plantation cycles without Mg application will lead to a low concentration of available Mg in the soil.

Magnesium (Mg) is crucial for plants. Approximately 75% of leaf Mg is involved in protein synthesis, and 15-20% of total Mg is associated with chlorophyll pigments, Mg act primarily as a cofactor of a series of enzymes responsible for photosynthetic carbon fixation and metabolism (Marschner, 1995). In plants, Mg^{2+} is a vital component of chlorophyll and is responsible for activating more than 300 enzymes (e.g., RNA polymerases, ATPases, protein kinases, phosphatases, glutathione synthase, and carboxylases). It also regulates ion transport and cation balance in plants (Bose et al., 2011). A ton of fresh latex rubber contains 5 kg of Mg (Kungpisdan, 2011). Therefore, continued rubber cultivation results in available soil Mg slowly decreasing through plant uptake for growing and production. The optimal available soil Mg is 0.30 $cmol_c$ kg^{-1}, but most rubber trees growing in Thailand only have access to Mg amounts lower than this optimal soil Mg level (Kungpisdan et al., 2013). In soil with low Mg content, kieserite ($MgSO_4 \cdot 7H_2O$) at the rate of 80 g $tree^{-1}$ $year^{-1}$ has been recommended for rubber plantations in Thailand (Rubber Research Institute of Thailand, 2019).

Potassium (K) is the macronutrient for the growth and latex production of a rubber tree. A ton of latex contained 25 kg of K (Kungpisdan, 2011). Excessive Mg application antagonises K uptake (Ding et al., 2006; Tandon, 1992). The application of a high dose of K fertiliser to soil also decreases the concentration of leaf Mg (Marschner, 1995). Conversely, excess Mg fertiliser application decreases leaf K concentrations (Kungpisdan & Buranatum, 1998). In fruits and vegetables, the ratios of Mg to K have proven to be more accurate in indicating the quality response than Mg status by itself (Gerendás & Führs, 2013). There have been no reports relating to the effects of Mg on growth and the antagonism between K and Mg in rubber tree saplings. Therefore, the balance between K and Mg in the soil needs to be studied. Therefore, the objectives of this study included the following: 1) to investigate the effect of the form of Mg administered on the growth and nutrient translocation in the soil to rubber saplings, and 2) to evaluate the optimal ratio of soil K: Mg. The knowledge gained from this research can lead to an improved understanding of Mg and K fertiliser management in rubber growing soils.

MATERIALS AND METHODS

Soil Sampling

Khlong Thom soil series (Km: Fine-loamy, kaolinitic, isohyperthermic Typic Kandiudults) was collected at a depth of 0-30 cm from rubber plantation soil in Songkhla province, Thailand. The soil samples were air-dried, passed through a 10-mesh sieve for physicochemical properties analysis, and then passed through a 3/4 mesh for pot experiments.

Effect of Dolomite and Kieserite Application on Growth of Rubber Tree Saplings

Budded stumps of the RRIM 600 rubber tree were planted in 30 L plastic pots filled with 28 kg of air-dried soil. The experiment used a completely randomized design (CRD) with five replicates containing five treatments each 1) without Mg application as the control treatment; 2-3) Mg application at the rates of 0.5 and 1.0 $cmol_c$ kg^{-1} in the form of dolomite ($CaMg(CO_3)_2$), and 4-5) Mg application at the rates of 0.5 and 1.0 $cmol_c$ kg^{-1} in the form of kieserite ($MgSO_4 \cdot H_2O$). The sources of N (100 mg N kg^{-1}) P (40 mg P_2O_5 kg^{-1}) and K (100 mg K_2O kg^{-1}) were added in the form of urea (46-0-0), triple superphosphate (0-46-0), and potassium chloride (0-0-60) as top dressings in all treatments for optimal nutrition levels. Distilled water was used for watering until harvesting (6 months).

Effect of K:Mg Ratio on Growth of Rubber Tree Saplings

Five treatments at different K:Mg ratios were applied (Table 1). Extractable K and Mg levels in the Khlong Thom soil series were 10.2 and 16.0 mg kg^{-1}, respectively. The K:Mg ratios (4.5:1, 2:1, and 3:1) were adjusted using KCl and kieserite to K_{72}:Mg_{16}, K_{72}:Mg_{36}, K_{108}:Mg_{36}, K_{180}:Mg_{36}, and K_{180}:Mg_{60}.

Table 1
Initial extractable K and Mg in soil and K:Mg ratio

Treatment	Ratio K:Mg	Initial concentration (mg kg^{-1})		Fertiliser application (g 28 kg^{-1} soil)	
		K*	Mg*	KCl	Kieserite
K_{72} : Mg_{16}	4.5:1	10.2	16.0	3.5	0.0
K_{72} : Mg_{36}	2:1	10.2	16.0	3.5	3.6
K_{108} : Mg_{36}	3:1	10.2	16.0	5.5	3.6
K_{180} : Mg_{36}	5:1	10.2	16.0	9.5	3.6
K_{180} : Mg_{60}	3:1	10.2	16.0	9.5	7.8

Note: * Initial extractable K and Mg concentrations in the soil before fertiliser application based on treatment.

Growth Rate

Sapling height and stem diameter at 10 cm above the bud union were recorded. The number of leaves, whorls and petioles were also recorded along with the rubber tree symptoms after dolomite and kieserite application. The differences in sapling height and stem diameter between the beginning and end of cultivation (6 months) were considered to compare the effect of dolomite and kieserite on the growth of the rubber tree saplings.

Soil and Plant Analysis

Soil samples passed through a 10 mesh sieve (particles < 2 mm) were used to analyse the soil pH (soil: water = 1:5 w/v), organic matter (Walkley and Black method), total N (Kjeldahl method), available phosphorus (Bray II) and extractable K, Ca, and Mg (1M NH_4OAc pH 7.0). In addition, plant sections consisting of the leaf, petiole, stem, primary root, and lateral root were separated. The plant samples were oven-dried at 80^{o}C for 72 h. Each plant section was weighed, ground, and passed through a 20 mesh sieve then digested with H_2SO_4 to calculate the total N (Kjeldahl method), and for mixed acid (HNO_3:$HClO_4$ = 3:1 v/v) for P, K, Ca, Mg, and S analysis (Jones Jr, 2001).

Statistical Analysis

The growth rates, nutrients in the soil, and the rubber tree saplings are presented herein as mean values of five replications with their standard deviations. The plant dried weights and nutrient concentrations were used to calculate the efficiency of plant nutrition uptake in the rubber tree saplings. Analysis of Variance (ANOVA) was used to test the difference among treatments. Means were separated using the Test of Mean Comparison, which is Duncan's Multiple Range Test (DMRT) at $P \leq 0.05$.

RESULTS

Soil Chemical Properties

After Mg application, the soil chemical properties revealed that the soil Mg concentrations significantly increased according to the Mg application rates (Table 2). However, Mg application rates of 0.5 and 1.0 $cmol_c\ kg^{-1}$ in the kieserite formula significantly increased the soil available Mg concentrations from 0.12 $cmol_c\ kg^{-1}$ (control) to 0.68 and 1.19 $cmol_c\ kg^{-1}$, respectively. While dolomite application significantly increased the Mg levels to 0.27 and 0.36 $cmol_c\ kg^{-1}$, respectively. Moreover, dolomite application at both 0.5 and 1.0 $cmol_c\ kg^{-1}$ increased the soils' available Mg level and enhanced their pH value from 4.6 to 5.1 and 5.6, respectively. The extractable Ca from 0.32 $cmol_c\ kg^{-1}$ to 0.49 and 0.60 $cmol_c\ kg^{-1}$, respectively.

Table 2
Soil chemical properties after dolomite and kieserite application

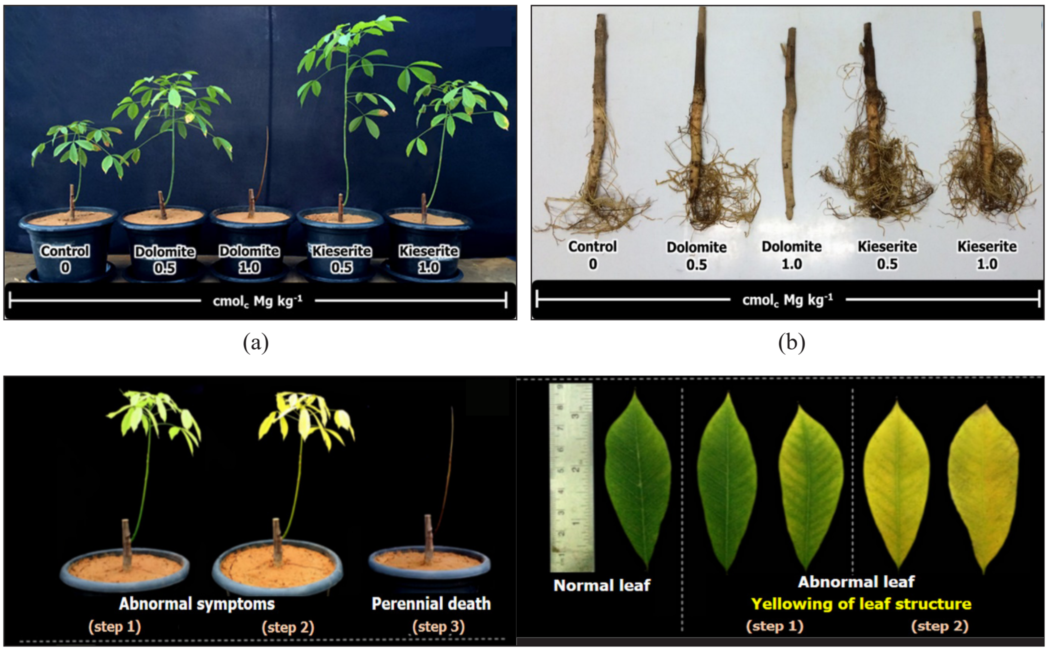
Treatment	pH (1:5)	EC (dS m^{-1})	Total N (g kg^{-1})	Avail. P (mg kg^{-1})	Extr. K	Extr. Mg	Extr. Ca
					[----------	$cmol_c$ kg^{-1}	----------]
Mg 0 $cmol_c$ kg^{-1} (control)	4.6±0.8 c	0.11±0.01 c	0.33±0.05	10.80±1.30	0.23±0.06	0.12±0.01 d	0.32±0.02 c
Mg 0.5 $cmol_c$ kg^{-1} (dolomite)	5.1±0.1 b	0.12±0.01 c	0.33±0.08	10.36±1.62	0.25±0.08	0.27±0.02 cd	0.49±0.03 b
Mg 1.0 $cmol_c$ kg^{-1} (dolomite)	5.6±0.2 a	0.12±0.01 c	0.36±0.06	9.27±1.51	0.25±0.04	0.36±0.01 c	0.60±0.03 a
Mg 0.5 $cmol_c$ kg^{-1} (kieserite)	4.6±0.1 c	0.19±0.01 b	0.34±0.04	10.87±2.43	0.26±0.06	0.68±0.20 b	0.35±0.03 c
Mg 1.0 $cmol_c$ kg^{-1} (kieserite)	4.5±0.1 c	0.26±0.01 a	0.37±0.06	10.03±1.82	0.26±0.04	1.19±0.19 a	0.34±0.02 c
F-test	*	*	NS	NS	NS	*	*
C.V. (%)	2.75	19.66	9.19	13.88	21.91	23.4	7.56

Note: * Significantly different ($P \leq 0.05$); NS = not significantly different ($P > 0.05$). Different letters in each column indicate significant difference by DMRT at $P \leq 0.05$

Effect of Dolomite and Kieserite on Growth of Rubber Tree Saplings

Dolomite and kieserite applications significantly promoted the growth of rubber tree saplings (Table 3). The height and diameter of the saplings tended to increase compared with the control, and the numbers of leaves, petioles, and whorls significantly increased following the application of both dolomite and kieserite. The number of leaves on the rubber tree saplings significantly increased by 9-20 leaves, the number of petioles by 9-19.5, and the number of whorls by 0.8-1 compared to the control treatment. However, the application of 1.0 $cmol_c$ Mg kg^{-1} of dolomite led to the yellowing of leaf structures between veins. While the veins remain green. These abnormal symptoms were similar to those typical of Mg deficiency but simultaneously occurred in the upper and lower leaves. Yellowing was apparent in the leaves, petioles, and stems. Later, those rubber tree saplings shed their leaves and died (Figure 1c).

Kieserite application significantly promoted the growth of the rubber tree saplings in terms of their shoots and roots (Figures 1a & 1b) more than the application of dolomite (Table 3). After 6 months, the height and stem diameter of the saplings treated with kieserite at an application rate of 0.5 $cmol_c$ Mg kg^{-1} displayed the highest values (51.01 cm and 3.69 mm, respectively). A kieserite application rate of 1.0 $cmol_c$ Mg kg^{-1} resulted in 30.33 cm and 2.07 mm, and the control treatment resulted in values of 26.72 cm and 1.31 mm, for height and stem diameter, respectively. Moreover, a similar effect was recorded for the numbers of leaves, whorls, and petioles.



(c)

Figure 1. Effect of dolomite and kieserite application on shoots (a) and roots (b) of rubber tree saplings and abnormal symptoms of rubber tree sapling (c) after dolomite application (1.0 cmol$_c$ kg^{-1})

Table 3
Effect of dolomite and kieserite on growth of rubber tree sapling

Treatment	Height (cm)	Diameter (mm)	Number of		
			Leaf	Petiole	Whorl
Mg 0 cmol$_c$ kg^{-1} (control)	26.72±3.25 b	1.31±0.55 b	13.50±2.58 b	25.50±2.54 b	1.00±0.20 b
Mg 0.5 cmol$_c$ kg^{-1} (dolomite)	28.13±2.58 b	1.85±0.68 b	22.50±4.77 ab	34.50±3.31 ab	1.80±0.40 a
Mg 1.0 cmol$_c$ kg^{-1} (dolomite)	ND	ND	ND	ND	ND
Mg 0.5 cmol$_c$ kg^{-1} (kieserite)	51.01±4.26 a	3.69±0.87 a	33.00±9.53 a	45.00±4.66 a	2.00±0.60 a
Mg 1.0 cmol$_c$ kg^{-1} (kieserite)	30.33±3.32 b	2.07±0.55 b	23.25±5.11 ab	35.25±8.54 ab	2.00±0.40 a
F-test	*	*	*	*	*
C.V. (%)	32.71	38.13	34.76	31.54	16.60

Note: * Significantly different ($P \leq 0.05$). Different letters in each column indicate a significant difference at $P \leq 0.05$ by DMRT. ND = No data because the rubber tree died. Each parameter value was calculated by considering the difference in values between the cultivation's beginning and end (6 months)

Dolomite application (0.5 $cmol_c$ Mg kg^{-1}) significantly increased the biomass (Table 4). The primary roots and petioles significantly increased to 28.29 and 1.67 g $tree^{-1}$, respectively. Whereas for the control treatment, it was 17.31 and 0.66 g $tree^{-1}$, respectively (Table 4). Kieserite application at both 0.5 and 1.0 $cmol_c$ Mg kg^{-1} significantly increased the dry weight of the above-ground biomass and the root sections (Table 4). Kieserite application at a rate of 0.5 $cmol_c$ Mg kg^{-1} significantly increased the primary roots, leaves, stems, lateral roots, and petioles to 51.22, 10.09, 12.48, 7.76, and 1.57 g $tree^{-1}$, respectively.

Comparing dolomite and kieserite (0.5 $cmol_c$ Mg kg^{-1}) revealed that kieserite application caused a significant increase in root and above-ground biomass to 58.97 and 24.14 g $tree^{-1}$, respectively. In contrast, dolomite application resulted in 30.96 and 11.87 g $tree^{-1}$ (Table 4).

Effect of Dolomite and Kieserite on Plant Nutrition Uptake and Total Chlorophyll Content

Dolomite application at the rate of 0.5 $cmol_c$ Mg kg^{-1} significantly increased leaf Mg concentration from 1.48 g kg^{-1} (control) to 3.85 g kg^{-1}. Leaf Ca concentration increased to 8.29 g kg^{-1}. Whereas for the control treatment, it was 5.18 g kg^{-1} (Table 5). Kieserite application rates of 0.5 and 1.0 $cmol_c$ Mg kg^{-1} significantly enhanced leaf Mg concentration to 4.09 and 4.50 g kg^{-1}, respectively. Whereas leaf Mg concentration in the control treatment was 1.48 g kg^{-1}. Moreover, kieserite application significantly increased leaf S from 0.67 g kg^{-1} (control) to 1.18 and 1.67 g kg^{-1} for kieserite application rates of 0.5 and 1.0 $cmol_c$ Mg kg^{-1}, respectively. However, kieserite applications of 0.5 and 1.0 $cmol_c$ Mg kg^{-1} significantly decreased K uptake from 20.01 g kg^{-1} to 15.79 and 12.58 g kg^{-1}, respectively. Total leaf Mg (4.09 g kg^{-1}) and leaf S (1.18 g kg^{-1}) for saplings that received 0.5 $cmol_c$ kg^{-1} application of kieserite were higher than that for saplings to which dolomite was applied (Mg 3.85 and S 0.75 g kg^{-1}, respectively). However, kieserite application significantly decreased leaf K content (15.79 g kg^{-1}) compared with dolomite application (20.07 g kg^{-1}) and the control treatment (20.01 g kg^{-1}). The chlorophyll concentrations in the saplings which received kieserite applications at the rates of 0.5 and 1.0 $cmol_c$ Mg kg^{-1} were 2.80 and 2.88 mg dm^{-2}, respectively, and were higher than those to which dolomite was applied at the rate of 0.5 $cmol_c$ kg^{-1} (2.08 mg dm^{-2}) and the control treatment (1.79 mg dm^{-2}).

Ratio of K:Mg on Plant Growth Rate and Nutrient Concentration in Leaves

The 2:1 ratio of K:Mg provided the greatest height and stem diameter not significantly increased between the beginning and end of cultivation (6 months) of the rubber tree saplings (Table 6). Increasing K application rates tended to significantly increase leaf K concentrations (Table 6). However, increasing the soil K application rates caused the Mg leaf concentrations to significantly decrease. Thus, the lowest leaf Mg concentration (1.26

Table 4
Effect of dolomite and kieserite on the dry weight of rubber tree sapling

Treatment	Dry weight (g tree^{-1})							
	Leaf	Petiole	Stem	Primary root	Lateral root	Shoot	Root	Whole plant
Mg 0 $cmol_c$ kg^{-1} (control)	5.12±1.82 b	0.66±0.22 b	4.28±1.37 b	17.31±2.75 c	2.57±0.13 b	10.06±2.64 b	19.88±2.67 c	29.45±8.82 d
Mg 0.5 $cmol_c$ kg^{-1} (dolomite)	5.89±2.15 b	1.67±0.66 a	4.32±1.53 b	28.29±4.19 b	2.68±0.50 b	11.87±3.00 b	30.96±4.64 b	42.84±7.53 c
Mg 1.0 $cmol_c$ kg^{-1} (dolomite)	ND	ND	ND	ND	ND	ND	ND	ND
Mg 0.5 $cmol_c$ kg^{-1} (kieserite)	10.09±2.36 a	1.57±0.90 a	12.48±2.86 a	51.22±3.54 a	7.76±2.83 a	24.14±5.50 a	58.97±1.80 a	83.11±8.59 a
Mg 1.0 $cmol_c$ kg^{-1} (kieserite)	6.71±1.51 b	1.39±0.82 a	12.51±0.74 a	33.03±2.65 b	3.57±0.77 b	20.61±2.37 a	36.60±3.35 b	57.21±2.11 b
F-test	*	*	*	*	*	*	*	*
C.V (%)	31.95	29.70	23.93	11.51	20.07	21.58	8.95	9.96

Note: * Significantly different ($P \leq 0.05$). Different letters in each column indicate a significant difference at $P \leq 0.05$ by DMRT; ND = No data because the rubber tree died

Table 5
Effect of dolomite and kieserite on leaf nutrient concentration and total chlorophyll content

Treatment	Leaf nutrient concentration						Total chlorophyll content
	N	P	K	Mg	Ca	S	
	[---------------------------- g kg^{-1}				----------------------------]		(mg dm^{-2})
Mg 0 $cmol_c$ kg^{-1} (control)	40.66±3.53 a	1.25±0.74	20.01±2.56 a	1.48±0.35 b	5.18±0.89	0.67±0.22 c	1.79±0.04 b
Mg 0.5 $cmol_c$ kg^{-1} (dolomite)	39.46±2.74 a	1.32±0.66	20.07±3.55 a	3.85±0.74 a	8.29±0.77	0.75±0.11 c	2.08±0.53 b
Mg 1.0 $cmol_c$ kg^{-1} (dolomite)	ND	ND	ND	ND	ND	ND	ND
Mg 0.5 $cmol_c$ kg^{-1} (kieserite)	40.93±3.11 a	1.42±0.25	15.79±2.66 b	4.09±0.84 a	4.85±0.62	1.18±0.32 b	2.80±0.21 a
Mg 1.0 $cmol_c$ kg^{-1} (kieserite)	33.71±1.85 b	1.30±0.51	12.58±3.41 c	4.50±0.77 a	5.19±0.58	1.67±0.57 a	2.88±0.37 a
F-test	*	NS	*	*	NS	*	*
C.V. (%)	24.23	11.08	13.33	19.96	34.32	23.53	16.05

Note: * Significantly different ($P \leq 0.05$); NS = not significantly different ($P > 0.05$). Different letters in each column indicate significant difference by DMRT at $P \leq 0.05$; ND = No data because the rubber tree died

Table 6
Effect of K:Mg ratio on growth rate and leaves nutrient concentration

Treatment	Ratio	Height[a] (cm)	Stem diameter[a] (mm)	N	P	K (g kg^{-1})	Mg	Ca
K_{72} : Mg_{16}	4.5:1	44.13 ± 3.53	5.55 ± 1.70	40.51 ± 4.31	0.48 ± 0.05	19.74 ± 1.60 b	3.67 ± 1.09 a	6.06 ± 0.82
K_{72} : Mg_{36}	2:1	49.56 ± 3.11	6.29 ± 2.20	36.16 ± 4.61	0.45 ± 0.20	21.41 ± 2.73 b	3.38 ± 1.22 a	6.48 ± 1.61
K_{108} : Mg_{36}	3:1	44.00 ± 5.22	6.17 ± 3.21	36.97 ± 5.73	0.54 ± 0.19	29.27 ± 2.63 a	3.20 ± 1.21 a	7.68 ± 0.58
K_{180} : Mg_{36}	5:1	38.80 ± 4.87	5.60 ± 2.77	41.41 ± 3.52	0.47 ± 0.11	27.82 ± 3.53 a	1.26 ± 0.19 b	7.61 ± 0.60
K_{180} : Mg_{60}	3:1	ND	ND	ND	ND	ND	ND	ND
F-test		NS	NS	NS	NS	*	*	NS
C.V. (%)		12.28	5.97	11.19	35.34	11.06	35.53	14.32

Note: * Significantly different ($P \leq 0.05$); NS = not significantly different ($P > 0.05$). Different letters in each column indicate significant difference by DMRT at $P \leq 0.05$; ND = No data because the rubber tree died

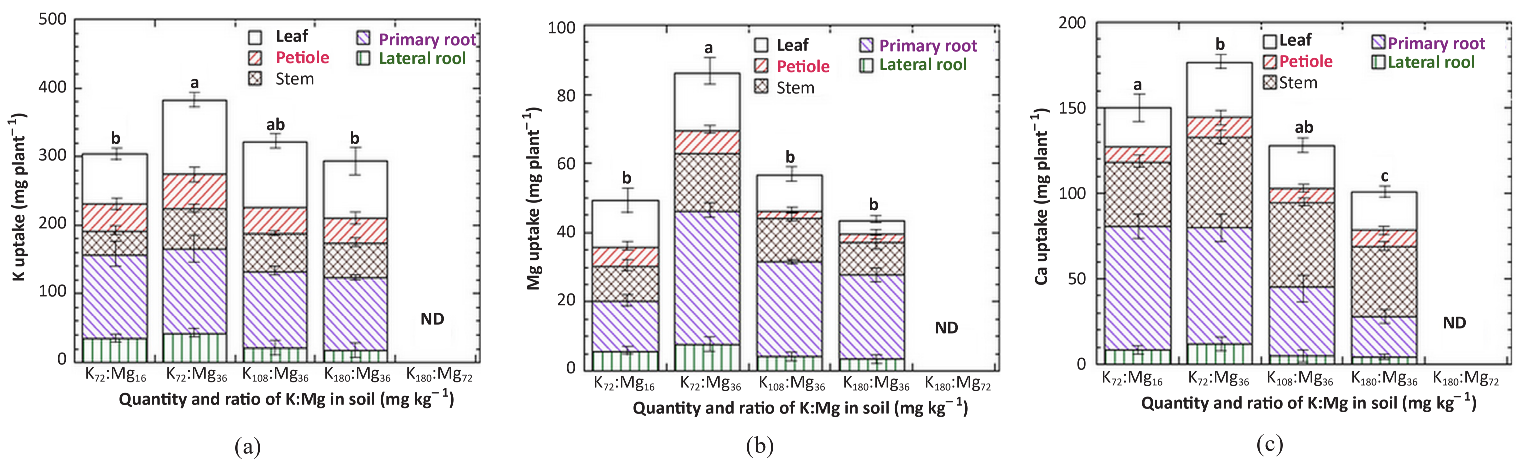


Figure 2. Effect of quantity and ratio of soil K: Mg (mg kg^{-1}) on K (a), Mg (b), and Ca uptake (c)
Note. ND = no data because the rubber tree died

mg kg^{-1}) resulted from a K application rate of 180 mg kg^{-1}, with Mg applied at a level at 36 mg kg^{-1} (ratio 5:1).

The primary roots had the highest K concentration, followed (in decreasing order) by leaves, stems, petioles, and lateral roots. The highest K uptake (333.53 mg tree^{-1}) occurred with the K application rate of 72 mg kg^{-1} with 36 mg kg^{-1} Mg (ratio 2:1). In contrast, the lowest K uptake (279.08 mg tree^{-1}) was recorded for the K application rate of 72 mg kg^{-1} with 16 mg kg^{-1} Mg (ratio 2:1) (Figure 2a). Plant K was lowest (43.27 mg tree^{-1}) based on a K application rate of 180 mg kg^{-1} with 36 mg kg^{-1} Mg (ratio 5:1). Mg uptake was highest (78.51 mg tree^{-1}) for the Mg application rate of 36 mg kg^{-1} with 72 mg kg^{-1} K (ratio 2:1). On the other hand, Mg uptake significantly decreased with an increasing K application rate (Figure 2b). The highest Mg content was found in the primary roots, followed (in descending order) by stems, leaves, petioles, and lateral roots (Figure 2b).

Ca uptake was highest in the primary roots, followed by (in descending order) stems, leaves, petioles, and lateral roots. Thus, the K application rate of 72 mg kg^{-1} with 36 mg kg^{-1} Mg (ratio 2:1) promoted the highest plant Ca content (166.14 mg tree^{-1}). Nevertheless, increasing the K application rate from 72 mg kg^{-1} to 108 and 180 mg kg^{-1} with Mg applied at 36 mg kg^{-1} (ratios of 3:1 and 5:1, respectively) caused sapling Ca to significantly decreased to 125.24 and 97.62 mg tree^{-1}, respectively (Figure 2c).

DISCUSSION

Soil Chemical Properties

Applying both dolomite and kieserite significantly increased the extractable Mg in the soil (Table 2). For the same rate of dolomite and kieserite application, the available soil Mg levels were higher in those to which kieserite was applied compared to those receiving dolomite. The solubility of kieserite in water is higher than that of dolomite. Therefore, the Mg content in the kieserite was liberated more rapidly than that of the dolomite. Moreover, the Mg content was gradually released, leading to improved plant growth in the saplings to which kieserite was applied (Figures 1a & 1b). Dolomite application significantly enhanced the level of available Mg in the soil and significantly increased the soil pH value and Ca concentration in soil (Table 2).

Growth of Rubber Tree Saplings and their Mg Concentration

The application of kieserite promoted the growth of the rubber tree saplings in terms of their height, stem diameter, number of leaves, whorls and petioles, and the dry weight of both their shoot and root sections (Tables 3 & 4) compared to those grown with dolomite application. In addition, the application of Mg in the soil significantly increased the leaves Mg (Table 5). The result is similar to the results for Mg application to para rubber

(Bueraheng et al., 2018), citrus (Xiao et al., 2014; Zheng et al., 2015), and rice (Ding et al., 2006). Mg is an element that is highly mobile in plants, particularly in green sections, such as leaves. Therefore, the application of Mg led to a significant increase in total chlorophyll in leaves (Table 5). This result was similar to those previously reported for Mg application in citrus (Xiao et al., 2014), rice (Moreira et al., 2015; Yuchuan et al., 2008), strawberry plants (Choi & Latigui, 2008), pepper (Anza et al., 2005) and maize (Jezek et al., 2015). Mg levels in leaves ranging between 0.25% and 1.0% are considered sufficient for plants (Yash, 1998). Kieserite contains an S content of 27%. In soils with a coarse texture and a low organic matter content, S deficiency is common (Brady & Weil, 2008). Therefore, kieserite application at rates of 0.5 and 1.0 $cmol_c$ Mg kg^{-1} significantly increased the S content in leaves (Table 5). Although the optimal S level for rubber has not been reported, the optimal leaf S was reported to be within a range of 2.5-10.0 g kg^{-1} for general plants (Yash, 1998).

Applying kieserite at a rate of 0.5 $cmol_c$ Mg kg^{-1} significantly decreased the K concentrations in leaves (Table 5). However, excess dolomite application (1.0 $cmol_c$ Mg kg^{-1}) caused the death of the rubber saplings (Figure 1a). The optimal soil available Mg for rubber plantations has been reported as being 0.08-0.21 $cmol_c$ Mg kg^{-1} (Krishnakumar & Potty, 1992). Therefore, rubber tree saplings receiving dolomite at the rate of 1.0 $cmol_c$ Mg kg^{-1} may have Mg toxicity on plant growth because of excess soil Mg. Moreover, excess Mg application inhibits translocation of other nutrients from roots to shoots (Marschner, 1995). These results are in line with previous studies, which have found that excess lime application led to negative effects on plant growth, particularly on maize and barley (Kovacevic et al., 2006), the growth of which tended to decrease after an increase in lime application rates.

In Mg deficient rice, leaves displayed decreased chlorophyll concentrations, photosynthetic activity, and soluble protein. However, leaf concentrations of soluble sugars and malondialdehyde (MDA) and the activities of superoxide dismutase, catalase, and peroxidase increased (Yuchuan et al., 2008). Moreover, it has been reported that Mg inhibition of root elongation has implications for hydroponic procedures when screening for Al tolerant soybean germplasm (Silva et al., 2001). In this study, excess dolomite application at a rate of 1.0 $cmol_c$ Mg kg^{-1} to the soil-grown rubber saplings led to their death after only 2 months. In the initial stage, light yellow colouration developed along the marginal veins of both the upper and lower leaves, similar to the symptoms of Mg deficiency. Subsequently, the leaves, petioles, and stems displayed yellow colouration and the saplings developed lateral root rot. In the final stage, the saplings shed their leaves, and death occurred (Figure 1c).

Effect of K:Mg Ratio on Growth and Nutrient Concentration in Leaves of Rubber Tree Saplings

Most soils in Thailand are acidic, with low K, Na, Ca, and Mg base saturation. Ion exchange equilibria, desorption and adsorption in acid soils are crucial to understanding crop production leaching and nutrient management dynamics. The antagonistic effect between soil Mg-K and Ca-K interaction can be explained by the differences in their ionic mobility and ion competition for plant uptake (Tandon, 1992). Therefore, excessive application of Mg to soil often reduces K translocation by plants (Tandon, 1992). In this research, K application rates ranging from 72 mg kg^{-1} to 108 and 180 mg kg^{-1} significantly enhanced K leaf concentrations (Table 6). Similar results have been reported in other studies with high rates of K fertiliser application in the soil also significantly increasing K concentrations in para rubber leaves (Kungpisdan & Buranatum, 1998). On the other hand, a high rate of K application to the soil significantly decreased the leaf Mg concentration (Table 6). This result was similar to those achieved with pummelo (Nguyen et al., 2016), cabbage, celery and lettuce (Inthichack et al., 2012), orchids (Poole & Seeley, 1978), and crested wheatgrass (Robbins & Mayland, 1993). Therefore, a high rate of K fertiliser application may cause an Mg deficiency in plants.

In Thailand, leaf Mg:K ratios in rubber grown in lowlands and uplands were 3.81:1 and 3.25:1, respectively. Whereas in the soils, they were 2.87:1 and 6.99:1 (Robbins & Mayland, 1993). While, the optimal K:Mg ratio in rice leaves has been found to range between 22 and 25 (Ding et al., 2006). Moreover, the exchangeable Ca:Mg ratio should be 6:1 in maize growing soils (Osemwota et al., 2007) and at a ratio of 1:2-1:1 for celery (Li et al., 2013). Further, the ratios of K:Mg-based on soil type were suggested as 1.2:1 in sandy soils, 1:1 in sandy loam and loamy soils, 0.7:1 in clay soils, and 2.2:1 in peat soils (Loide, 2004), which accords with the findings in the present study that a ratio of K:Mg of 2:1 in sandy loam was suitable for promoting nutrient uptake in rubber trees (Figure 2).

Further, K caused negative interaction between Mg and Ca. Therefore, a high soil K concentration affects Mg translocation from soil to plant. The inhibition of Mg uptake from K fertilisation reduced leaf tissue concentrations of Mg and the development of bacterial spots in tomato plants (Engelhard & Woltz, 1989). Moreover, the Ca:Mg ratio in the culture solution for soybean plants which promotes the best growth, was found to be 3:10 (Hashimoto, 2012). Therefore, the quantity and ratio of K and Mg should be considered in fertilisation in rubber growing soils because K and Mg management is important in promoting growth and plant health.

CONCLUSION

Mg application in the form of kieserite and dolomite significantly promoted rubber tree growth. The results indicated that rubber trees grew better following the application of kieserite than after the application of dolomite. Moreover, kieserite application was beneficial for chlorophyll and S content. The optimal Mg application rate was found to be 0.5 $cmol_c$ Mg kg^{-1} in the form of kieserite and at a ratio of K:Mg of 2:1, which was suitable for promoting rubber tree growth. However, further study of the S sensibility from kieserite application is required to increase knowledge regarding the management of rubber growing soils.

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