Agr. Nat. Resour. 55 (2021) 15–22

AGRICULTURE AND NATURAL RESOURCES

Journal homepage: http://anres.kasetsart.org

Research article

Effect of Mg rates from different sources on cassava grown in Typic Paleustults

Apitsara Charoenphon†, Suphicha Thanachit*, Somchai Anusontpornperm†, Irb Kheoruenromne†

Department of Soil Science, Faculty of Agriculture, Kasetsart University, Chatuchak, Bangkok 10900, Thailand

Article Info

Article history:
Received 9 December 2019
Revised 5 March 2020
Accepted 8 March 2020
Available online 31 January 2021

Keywords:
Dolomite,
Loamy sand soil,
Magnesium chloride,
Tropical soil

Abstract

Three Typic Paleustults with low available Mg status, namely Yasothon (Yt), Warin (Wn), and Satuk (Suk) soil series, were selected for the study on the response of cassava to different rates of magnesium (Mg) from different sources. All field trials were similarly arranged in a randomized complete block design, having four replications with treatments comprising two sources of Mg fertilizer, dolomite and magnesium chloride ($MgCl_2$) being applied at four rates, 0, 50, 100 and 200 kg Mg/ha. Results revealed that Mg content in selected soils before planting was insufficient for cassava due to the plot with no Mg addition in all soils statistically giving the lowest plant yield components. Cassava responded rather more positively to the rate of Mg applied than to the Mg sources. Cassava grown in chosen soils had a significant response Mg at varying rates of 50 to 200 kg Mg/ha. Dolomite was potentially a better source of Mg than $MgCl_2$ in terms of increasing growth and yield of cassava, particularly in Wn soil series. Both Mg fertilizers added at the rates between 50–100 kg Mg/ha significantly promoted cassava to take up and accumulate more Mg and Ca in plant tissues. Relative tuber yield and aboveground biomass were better correlated with only major plant nutrients in leaf and branch than in other cassava plant parts.

Introduction

Magnesium (Mg), an essential element for plant growth, is a component of chlorophyll and thus is necessary for photosynthesis (Chen et al, 2017). Magnesium is generally present in most soils in adequate amounts for crop requirement but in tropical soils with coarse texture nature and acidic condition, Mg is often loss by leaching and erosion (Ogawa et al, 1975; Schulte, 2004). Consequently, Mg becomes insufficient for plant growth. In Thailand, these types of soil are widely distributed in the northeast and generally used for cassava crop cultivation (Duangpatra, 1998). Moreover, the continuously repeated crop cultivation for many years without adequate fertilization and soil improvement has led to a drastic decrease in soil-plant nutrients of which Mg is included. This can be a reason that has limited cassava yield improvement for a decade as shown by the average cassava yield of the region that is lower than that in other regions and the plant's yield potential (Office of Agricultural Economics, 2018).

Magnesium deficiency symptom in most plants obviously shows interveinal chlorosis in older leaves, beginning firstly at the tips and margins, and later the symptoms spread inward, covering the entire portion of the area in between the veins. The necrotic and developed whitish color of leaves is seen in the severe Mg deficiency plant (Maguire and Cowan, 2002). In the case of cassava, plant responds by reduction in plant growth and appearance of interval chlorosis of lower leaves (Howeler, 1978; Howeler, 1985a) reported that Mg concentration in cassava leaves, mature leaf at 4 months of age,

† Equal contribution.
* Corresponding author.
E-mail address: suphicha.t@ku.ac.th (S. Thanachit)

https://doi.org/10.34044/j.anres.2021.55.1.03

below 0.15%, was insufficient for cassava growth. However, toxicity level of Mg was not indicated. Most of Mg in soils is mainly found in a component of several minerals and provide available Mg, Mg^{2+} ion, through weathering process (Mayland and Wilkinson, 1989). The available Mg is mostly presented in soil solution and partly adsorbed by soil colloid where the soluble Mg is readily leached out from rooting zone. The other sources, rock-forming minerals and fertilizers that contain Mg, could alternatively be available sources to provide Mg for plant (Gransee and Führs, 2013; Senbayram et al., 2015). However, there is no relevant data on time and amount of Mg dissolved from these materials to be available for cassava.

Moreover, the research related to the effects of Mg on cassava was limited, especially in Thailand. A report of Centro International de Agriculture Tropical (CIAT), 1985 only showed that cassava responded to Mg fertilizer when the soil extractable Mg content was lower than 24 mg/kg. Cassava showed a significant response to the highest level of 60 kg Mg/ha, but there was no significant differences among Mg sources such as serpentine, $MgSO_4$, and MgO. However, MgO was tentatively better when broadcasted. Therefore, our research was conducted with the aim at determining the effect of different rates of Mg from different sources on cassava grown in low fertile soils. Results of the study should be providing an appropriate rate of Mg fertilizer from specific Mg source that can be used as a guidance for increasing cassava yield.

Materials and Methods

Study area and soil properties

Field trials in this research were conducted in farmer fields, Nakhon Ratchasima province, northeast, Thailand. This province has the largest cassava planting areas in the country. Representative soils of the experimental areas were Warin (Wn) and Satuk (Suk) soil series located at Ban Supplu Noi, Huay Bong subdistrict, Dan Khun Thot district, and Yasothon (Yt) soil series situated at Ban Dong Krasang, Takhian subdistrict, Dan Khun Thot district. All studied soils were classified as Typic Paleustults, having sand to loamy sand texture. They were strongly acid to extremely acid (pH 4.74–5.74) with low contents of organic matter (3.10–5.16 g/kg), available P (3.23–6.02 mg/kg), available K (1.61–1.76 mg/kg), and available Mg (20.7–42.5 mg/kg) (Table 1)

Magnesium fertilizer from different sources and their solubility

Magnesium Chloride ($MgCl_2$) and dolomite were used as Mg sources in this study, which, they were composed of 21.27 and 46.52% of total Mg, respectively. The dissolution of Mg fertilizer in water was examined using a mixture between Mg fertilizer and water at the ratio of 1:100. These two Mg fertilizer sources were completely soluble in water within 48 hr of intensive stirring, where $MgCl_2$ had greater solubility than did dolomite as indicated by the former almost dissolving in water within a stirring time of 720 min whereas the latter dissolving within 1440 min (Fig. 1). Total Mg content dissolved from Mg fertilizers after continuous stirring for 48 hr showed that the amount from dolomite was significantly greater than that from $MgCl_2$, 43.8 compared with 33.83 mg/kg, respectively, due to the content of Mg in the former being much lower than in the latter. This can be interpreted that $MgCl_2$ was potentially a better Mg source for plants in a short period, while dolomite can be a supply of Mg for a more extended period. In addition, dolomite eventually gave more quantity of Mg than $MgCl_2$ when applied at the same rate. However, the nutrient release characteristics from Mg fertilizer source is of essential for the sustained supply of Mg to cassava.

Field experiment and crop cultivation

All field trials were carried out in each area from June 2017 to April 2018. The experiment was laid out as a randomized complete block, having 4 replications and 6-treatment combinations with zero application of Mg setting up as a check plot. Two forms of Mg fertilizer, dolomite and $MgCl_2$, were compared, each being applied at three rates, 50, 100 and 200 kg Mg/ha. Cassava, Huay Bong 80 variety, a popularly high yield variety commonly grown in the region was used as a tested plant. Cassava was planted on the ridge with a spacing of 80×120 cm at the beginning of rainy season. Magnesium fertilizer with respect to treatments and 100-50-100 kg N-P_2O_5-K_2O/ha, all fertilizers were applied at the same time, 2 months of age, for all plots. All fertilizers was added into a small hole, on the top of ridge in between two plants,

Table 1 Selected property of the studied soils

Soil Properties	Soil series		
	Yt	Wn	Suk
Textural class	Sandy loam	Loamy sand	Sandy loam
Sand (g/kg)	814	859	778
Silt (g/kg)	68	23	117
Clay (g/kg)	118	118	105
Soil-pH (1:1 H_2O)	4.78	4.74	5.74
Organic matter[1] (g/kg)	4.82	5.16	3.10
Available P[2] (mg/kg)	3.23	5.41	6.02
Available K[3] (mg/kg)	1.61	1.76	1.71
Extractable Mg[3] (mg/kg)	42.5	24.3	20.7
Extractable Ca[3] (mg/kg)	12.3	24.0	44.0
Extractable S[4] (mg/kg)	15.57	15.74	16.62
CEC[3] ($cmol_c$/kg)	1.6	1.8	1.3

[1]Walkley and black tritation method; [2]BrayII method; [3]1N NH_4OAC at pH 7.0 method; [4]$Ca(H_2PO_4)$ extraction

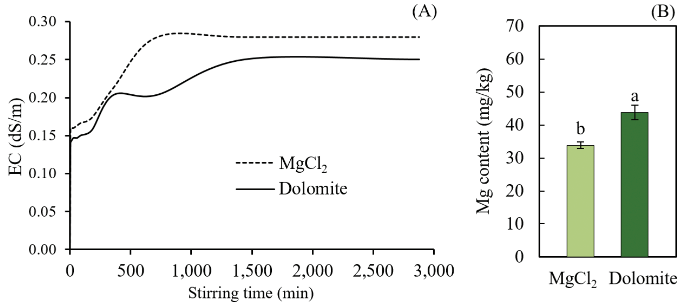


Fig. 1 Water solubility of the Mg fertilizers determined after continuous stirring by measuring the water conductivity; (A) Water solubility of Mg fertilizers and (B) the content of dissolved Mg, after continuously stirring for 48 hr

made by hand hoe then buried with soils. Nitrogen, P, K fertilizers were applied in the form of urea (46-0-0), di-ammonium phosphate (18-46-0) and potassium chloride (0-0-60), respectively.

Plant growth parameters and plant sampling

Cassava yield and plant parameters were harvested and recorded when cassava was 10 months old. Samples of different plant parts such as leaf and branch, stem, stem base and tuber, were collected at the harvesting time. Samples were oven dried at 60°C, ground and analyzed for total plant nutrient concentration by using standard methods. Removed and returned Mg of soils were calculated by multiplying the quantity of dry matter of each plant part with Mg concentration.

Statistical analysis:

Cassava yield components and Mg concentration in soils were analyzed for statistical significance using the analysis of variance (ANOVA). To determine the significance of the difference between the means of the treatments, Duncan multiple range test was computed at the 0.05 probability level ($p<0.05$) using SPSS program software.

Results and Discussion

Fresh tuber yield, starch yield, and starch content

Cassava grown in Wn soil series showed clear response to Mg fertilizer sources. The application of dolomite significantly stimulated higher fresh tuber and starch yields (31.81 and 8.94 t/ha) than did $MgCl_2$ (26.13 and 7.25 t/ha) (Fig 2). Dolomite was superior to $MgCl_2$ when applied to acidic and Ca deficient soils because $MgCl_2$ was easily dissolved and immediately released Mg into soil solution, then leached away rather more easily. In contrast, dolomite performed like a Mg slow-release fertilizer of which Mg was released steadily more slowly, preventing the loss of Mg in soil solution via leaching and enabling cassava to take up more Mg. As a result, better response of cassava was observed. Rather similar trends were also observed in the case of Yt and Suk soil series but without statistical differences among treatments (Fig. 2). The result was agreed with (Castro and Crusciol, 2015), who found that dolomitic lime was the most economical source for Mg under tropical conditions. Also, (CIAT, 1985) reported similar results of which cassava significantly responded differently to different Mg sources such as serpentine, $MgSO_4$, and MgO.

The application of Mg fertilizer clearly increased cassava yields when planted in all soils in this study as the significantly lowest yield was obtained in the control plot without Mg application. In the case of Yt soil series, the application of Mg fertilizer at different rates from 50 to 200 kg/ha gave no statistical difference in starch contents of 26.7–29.1% while the application at the rates of 50 and 100 kg Mg/ha significantly induced the highest cassava fresh tuber and starch yields of 4.94–5.06 and 1.31–1.50 t/ha, respectively (Fig. 2). This result agreed with previous report by Ngongi (1976) who found that a significant response to application of 50 kg Mg/ha as $MgSO_4\ 2H_2O$ or MgO with the former being superior, probably due to its S content and grater solubility but the application above 50 kg/ha resulted in a yield decrease due to the induction of Ca deficiency. The similar response was found in Suk soil series, but the significantly highest fresh tuber (34.38–36.06 t/ha) and starch (9.88–10.00 t/ha) yields were obtained from the plot fertilized with 100 and 200 kg Mg/ha, especially in the form of $MgCl_2$ (Fig. 3).

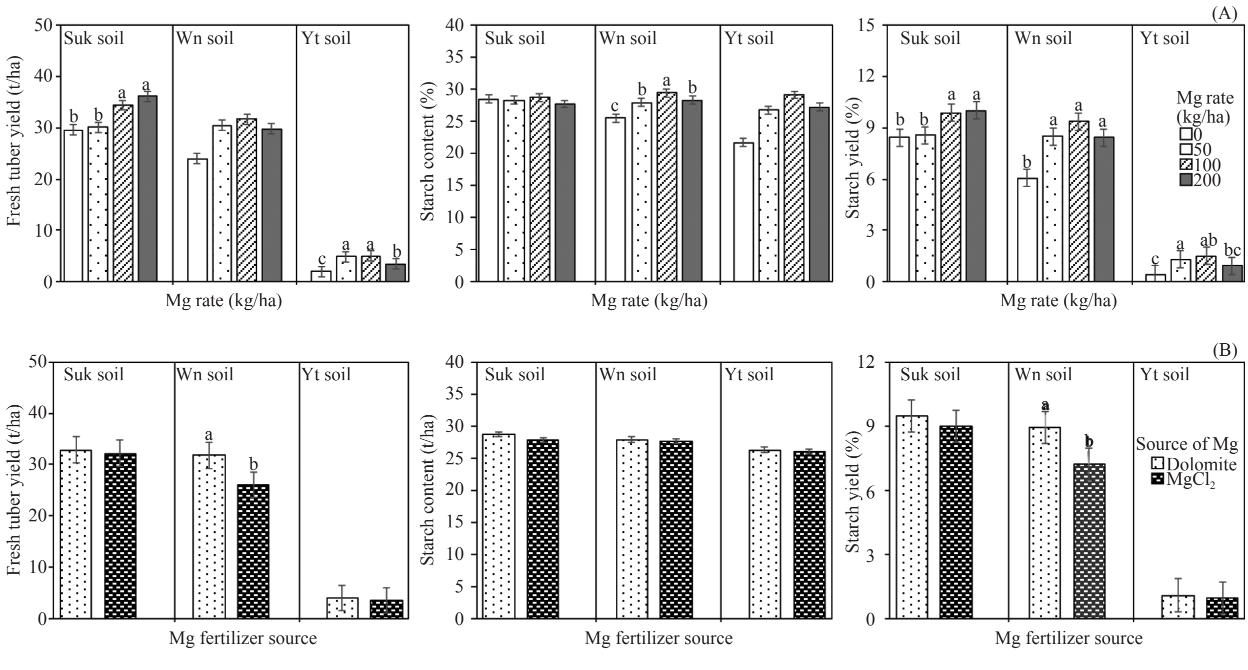


Fig. 2 Cassava yield components obtained from the three soil series; (A) Effect of Mg fertilizer rates and (B) effect of Mg fertilizer source.
Different lowercase letters above bars in the same soil series indicate significant difference ($p<0.05$) among means of each trait. Bars without lowercase letters indicate no significant difference.

The application of Mg at different rates gave no impact on fresh tuber yield (24.0–31.69 t/ha) of cassava grown in Wn soil series but gave a higher starch yield than did no application of this fertilizer (6.06 t/ha) however there was no significant difference among the rates of 50 to 200 kg Mg/ha in this context (8.43–9.38 t/ha). In addition, the significantly highest starch content of 29.4% was detected in this soil with the addition of 100 kg Mg/ha (Fig. 2). The results clearly showed that Mg enhanced the growth and yield of cassava. Cassava was reportedly sensitive to Mg deficiency, especially in soil with low K content (Howeler, 1978) as of the soils in this study. Magnesium plays an important role in the accumulation of starch in cassava tuber (Howeler, 1985a). Magnesium deficiency decreases the starch content in tuber due to limited translocation of sugar and carbohydrate but increasing accumulation of inorganic phosphorus instead (Maguire and Cowan, 2002; Schulte, 2004), resulting in a reduction in starch synthesis.

Aboveground biomass of cassava

Only cassava grown in Suk soil series showed clear response to different rates and sources of Mg fertilizer where the application of $MgCl_2$ at the rate of 50 kg Mg/ha statistically gave the lowest aboveground biomass content of 8.36 t/ha. Using $MgCl_2$ as Mg source at the rate of 200 kg Mg/ha significantly gave the highest contents of leaf and branch, stem base and net aboveground biomass of 9.75, 5.25 and 18.69 t/ha, respectively. Moreover, dolomite applied at all rates significantly promoted the higher aboveground biomass (12.25–13.25 t/ha) than did the control but with no statistical difference of this yield among plots treated with Mg (Fig. 4).

Since the studied soils had quite similar properties, the response of cassava to Mg application was quite similar, however, fresh tuber yield, starch yield and aboveground biomass of cassava obtained from Yt soil series were lower than from the other two soils (Figs 2-4). This was due mainly to this Yt soil series is generally formed on the higher position than Wn and Suk soil series, thus the soil tends to experience moisture deficit more regularly. Inferior cassava yields in this soil were previously reported (Riyaphan et al., 2010; Promma et al., 2012; Kaewkamthong et al., 2014; Wongbumru et al., 2016).

Plant nutrient concentration in cassava plant parts

Magnesium, Ca and K concentrations in different plant parts of cassava differed to some extent. Potassium concentrations in cassava plant parts planted in most soils were not affected by Mg fertilizer applied at different rates while increasing rates of Mg increased Mg and Ca concentrations. Moreover, using $MgCl_2$ as Mg source increased greater nutrient concentrations in cassava plant parts than did dolomite when applied at the same rate, especially at the rates of 100 and 200 kg/ha (Fig. 5). This result corresponded to previous report (Howeler, 1985b) which illustrated that increasing the level of Mg had no effect on leaf concentration of K but slightly decreased the concentration of Ca. Although, the antagonistic effects between Mg, and Ca and K were reported to reduce crop yield and quality due to competitive uptake, roots usually take K up more rapidly than Mg in

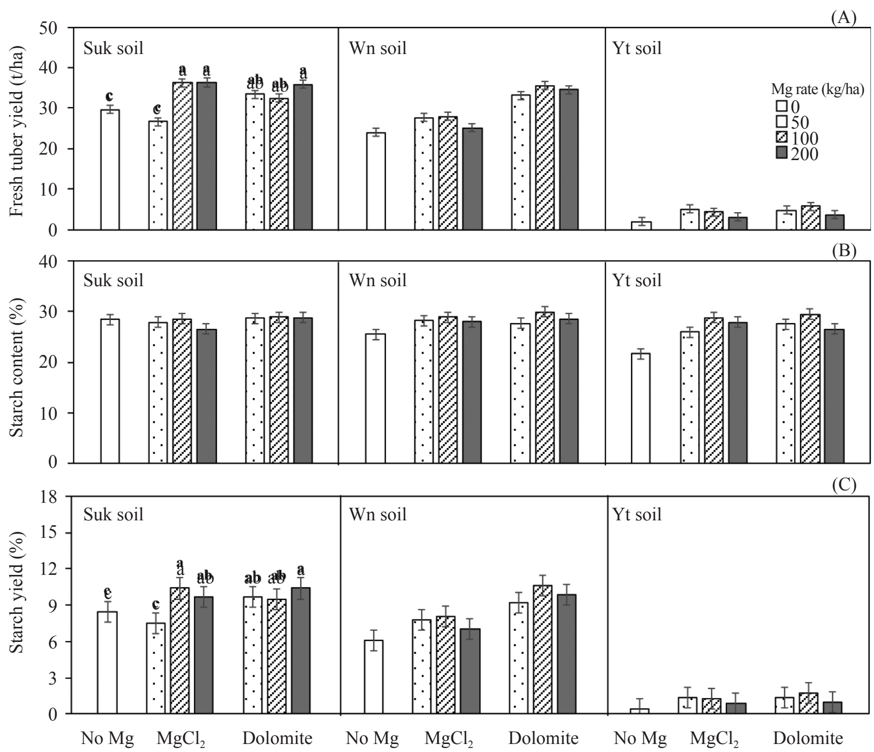


Fig. 3 Interactive effect of rates and sources of Mg fertilizer on cassava yield components: (A) Fresh tuber yield, (B) starch content, and (C) starch yield. Different lowercase letters above bars in the same soil series indicate significant difference (p<0.05) among means of each trait. Bars without lowercase letters indicate no significant difference.

addition to Ca inhibiting the entry of Mg in the roots due to similar ionic charge (Narwal et al., 1985).

Plant nutrients mostly accumulated more in cassava leaf and branch than in other plant parts (Fig. 5). Apart from cassava leaf and branch, high concentration of K was found in cassava tuber while Ca and Mg mostly accumulating in cassava stem. This was due to K being essential for the translocation of carbohydrates to cassava tuber. Calcium is required for various structural roles in the cell wall and membranes of plants. Moreover, Ca and Mg is slightly mobile in plant phloem, resulting in much of these nutrients being retained in cassava stem.

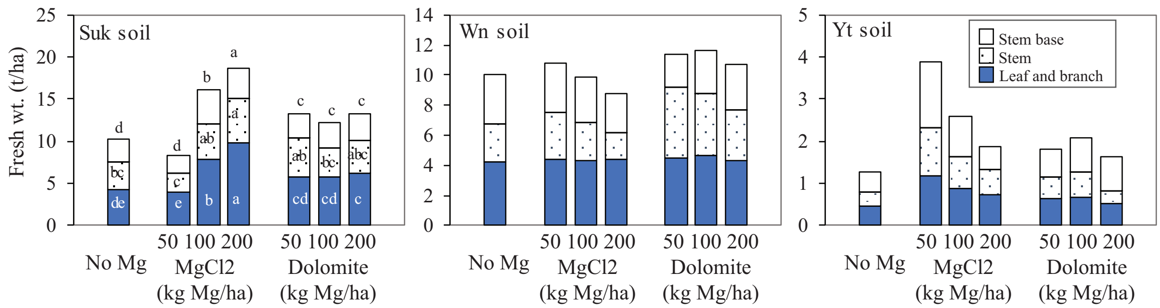


Fig. 4 The effect of rates and sources of Mg fertilizer on aboveground biomass of cassava
Different lowercase letters above and within the bars in the same soil series denote significantly difference (p<0.05) among mean values of each trait. Bars without lowercase letters indicate no significant difference.

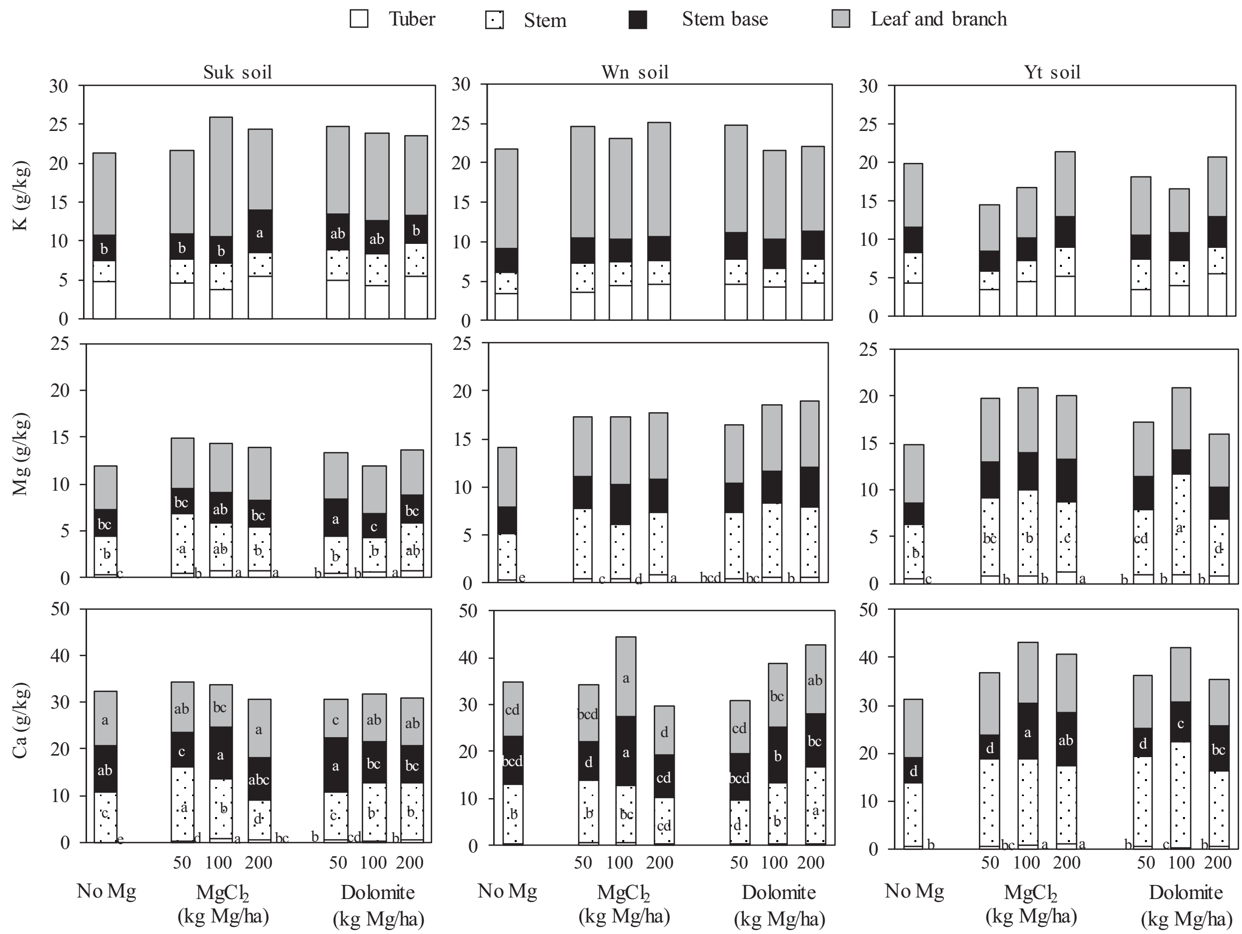


Fig. 5 The effect of rates and sources of Mg fertilizer on K, Mg and Ca concentrations in different plant parts of cassava
Different lowercase letters above and within the bars in the same soil series denote significantly difference (p<0.05) among mean values of each trait. Bars without lowercase letters indicate no significant difference.

Plant nutrient concentrations in relation to cassava yield components

Plant nutrient concentration in leaf and branch showed better statistical correlation with cassava yield parameters than that in other plant parts (Table 2). Relative cassava tuber yield and aboveground biomass highly significantly had a positive correlation with the concentrations of N (r = 0.38** and 0.59**), P (r = 0.34** and 0.53**) and K (r = 0.60** and 0.56**), respectively, in cassava leaf and branch. Phosphorus concentration in stem base also positively correlated with respective relative cassava tuber yield and aboveground biomass (r = 0.62** and 0.44**) with N concentration in this plant part highly significantly showing a positive correlation with relative aboveground biomass (r = 0.45**). Magnesium concentration in all plant parts showed no positive correlation with these two relative plant parameters. Magnesium is a component of chlorophyll and essential for photosynthesis (Chen et al., 2017) and a recent study showed that cassava took up Mg rapidly at the early stage of growth within one and a half month of age (Charoenphon et al., 2020). As a result, Mg concentration in plant parts at mature stage had no correlation with cassava yield components. Additionally, there was only Ca concentration in stem base that positively correlated with relative cassava tuber yield and aboveground biomass but the correlation was rather weak (r = 0.27* and 0.29*, respectively).

Magnesium removal and return of soil

The loss of soil Mg by crop removal was higher in cassava stem (1.83–27.40 kg/ha) than in cassava tuber (0.88–27.77 kg/ha) in all three soils. Cassava grown in soils without Mg application significantly removed the lowest Mg contents in both plant parts. Increasing rates of Mg significantly increased removed Mg in cassava stem (3.01–6.84, 17.53–27.4, and 16.70–21.99 kg/ha for Yt, Wn and Suk soil series, respectively) and cassava tuber (3.40–4.35, 15.83–22.66, and 16.70–21.99 kg/ha for Yt, Wn and Suk soil series, respectively) (Fig. 6). Nevertheless, in control plot without Mg application, plants removed higher Mg than that in the initial soils due to during growth stage of cassava, Mg could additionally be released from non-exchangeable form and become available to the plant, giving a possibility that Mg removed by the plant was higher than initial total extractable content of soil Mg in zero application of Mg treatment.

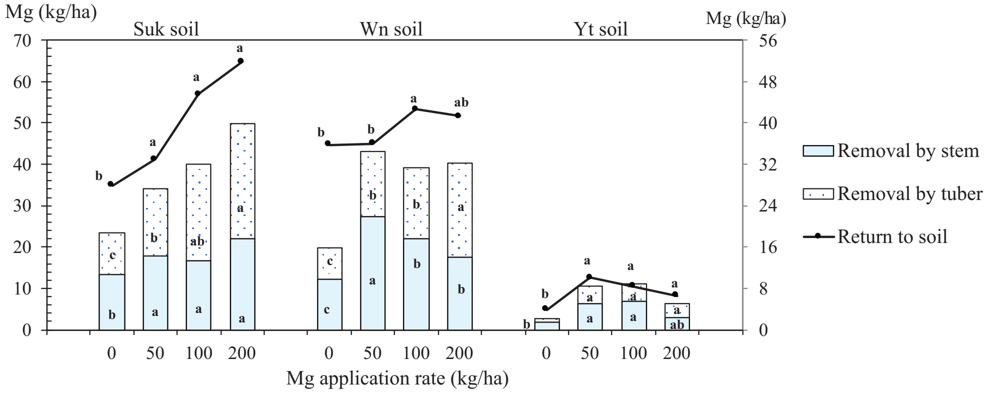
Generally, cassava fresh tubers are taken away from the field for selling purpose and cassava stems are used as planting material in the next growing season some in the area and/or some elsewhere. This can be the main reason that leads to a gradual decrease of soil Mg to the level that at some point Mg becomes a limiting factor for cassava cultivation in these soils. In the case of cassava leaf and branch, this plant part is always left in the field after the harvest and then incorporated into the soil during land preparation for the next crop. This means plant nutrients, including Mg, stored in this plant part is always returned to the soil. Regarding Mg uptake in this plant part, the application of Mg at all rates significantly gave higher contents of Mg returned to the soil than did the control plot with no Mg addition. Nonetheless, there was no statistical difference when compared among plots fertilized with different rates of Mg in both Suk and Yt soil series. In Wn soil series, the significantly highest retuned Mg to the soil was found when applied with 100 kg Mg/ha whereas the other rates showed no statistical difference to the control plot (Fig. 6).

However, contents of Mg returned to the soil was higher than Mg removal by cassava for all three studied soils, especially in the plots applied with Mg fertilizer (Fig. 6). This demonstrates that Mg fertilizer is essentially required when grown cassava in these soils but after having applied for a few years, the level of soil Mg should be sufficient because of Mg being released from annually incorporated leaf and branch residues; hence Mg fertilization might not be needed for the next few years after that. However, the content of Mg in these soils should be monitored, possibly in every 4–5 years to ensure that the level is enough for optimum growth of cassava.

Table 2 Correlation coefficient (*r*) for a linear relationship between plant nutrients accumulated in cassava plant part and relative yields of cassava.

Element	Correlation coefficient (r)			
	Tuber	Stem	Stem base	Leaf and branch
Relative tuber yield (%)				
N	0.14	-0.66**	0.14	0.38**
P	-0.17	-0.30**	0.62**	0.34**
K	-0.11	0.01	0.02	0.60**
Mg	-0.52**	-0.21	0.001	0.13
Ca	-0.41**	-0.57**	0.27**	-0.29**
Relative aboveground biomass (%)				
N	0.25*	-0.58**	0.45**	0.59**
P	-0.19	-0.13	0.44**	0.53**
K	0.09	0.12	0.22	0.56**
Mg	-0.35**	-0.39**	0.08	-0.14
Ca	-0.31**	-0.54**	0.29*	-0.46**

*,** Correlation are significant at $p \leq 0.05$ and 0.01 level, respectively. n = 84



†Fig. 6 The effect of Mg fertilizer rates on Mg removal and return to soil.
Bars represent mean of Mg removal by stem and tuber; the values are shown on the primary Y-axis on the left-hand side.
Black circles (on line graphs) represent mean of Mg return to soil, the value is shown on the secondary Y-axis on the right-hand side.
Different lowercase letters above the black circles and within the bars in the same soil series indicate significant difference ($p<0.05$) among means of each trait.

Magnesium fertilizer clearly enhanced cassava growth and promoted cassava to accumulate more Mg, and Ca, leading to an appreciable biomass and root yield production. The optimum rate differed among different soil series selected in the study. However, cassava mostly responded best to the rate of 100 kg Mg/ha; hence, this can be the most suitable rate and recommendable for cassava grown in these light-textured Typic Paleustults. Dolomite was a better source of Mg for than $MgCl_2$ in terms of increasing growth and yield of cassava despite $MgCl_2$ dissolving more easily. Relative tuber yield and aboveground biomass were correlated with only in the case of major plant nutrients in leaf and branch than in other cassava plant parts. Moreover, soil Mg level should be monitored after applying Mg fertilizer for a few years as some Mg can be released from high-Mg concentration leaf and branch incorporated into the soil annually.

Conflict of Interest

The authors declare that there are no conflicts of interest.

Acknowledgments

This research is supported partly by the Graduate Program Scholarship from The Graduate School, Kasetsart University, and Kasetsart University Research and Development Institute. The authors would also like to thank Thai Central Chemical Public Company Limited for contributing chemical fertilizers.

References

Castro, G.S.A., Crusciol, C.A.C. 2015. Effects of surface application of dolomitic limestone and calcium-magnesium silicate on soybean and maize in rotation with green manure in a tropical region. Soil and Plant Nutrition. 74: 311–321. doi.org/10.1590/1678-4499.0346

Charoenphon, A., Thanachit, S., Anusontpornperm, S., Kheoruenromne, I. 2020. Dissolution of Mg fertilizer and its availability in cassava in tropical upland soils. Communications in Soil Science and Plant Analysis. 51: 236–249. doi.org/10.1080/00103624.2019.1705327

Chen, Z.C., Peng, W.T., Li, J., Liao, H. 2018. Functional dissection and transport mechanism of magnesium in plants. Seminar in Cell and Developmental Biology. 74: 142–152. doi.org/10.1016/j.semcdb.2017.08.005

Centro International de Agriculture Tropical (CIAT). 1985. Cassava program. Annual Report for 1982 and 1983. CIAT, Cali, Colombia.

Duangpatra, P. 1998. Soil and Cassava Fertilizers. Kasetsart University, Bangkok.

Gransee, A., Führs, H. 2013. Magnesium mobility in soils as a challenge for soil and plant analysis, magnesium fertilization and root uptake under adverse growth conditions. Plant and Soil. 368: 5–21. doi.org/10.1007/s11104-012-1567-y

Howeler, R.H. 1985a. Mineral nutrition and fertilization of cassava, pp: 249320–. In: Cassava, Research, Production and Utilization. UNDP-CIAT Cassava Program, Cali, Colombia.

Howeler, R.H. 1985b. Potassium nutrition of cassava, pp: 819841–. In: Potassium in Agriculture. International Symposium, Atlanta, GA, 7–10 July. ASS, CSSA, SSSA, Madison, Wisconsin, USA.

Howeler, R.H. 1978. Nutritional Disorder of Cassava. Dept. Agri. Univ. Queensland, Australia.

Kaewkamthong, Y., Thanachit, S., Anusontpornperm, S., Wiriyakitnateekul, W. 2014. Alleviation of soil compaction problem for growing cassava on a Typic Paleustult, Northeast Thailand. Asian Journal of Crop Science. 6: 334–344. doi.org/10.3923/ajcs.2014.334.344

Maguire, M.E., Cowan, J.A. 2002. Magnesium chemistry and biochemistry. Biometals. 15: 203–210. doi.org/10.1023/A:1016058229972

Mayland, H.F., Wilkinson, S.R. 1989. Soil factors affecting magnesium availability in plant–animal systems: A review. J. Anim. Sci. 67: 3437–3444. doi.org/10.2527/jas1989.67123437x

Narwal, R.P., Kumar, V., Singh, J.P. 1985. Potassium and magnesium relationship in cowpea (*Vigna unguiculata* (L.) Walp.). Plant and Soil. 86: 129–134. doi.org/10.1007/BF02185032

Ngongi, A.G.N. 1976. Influence of some mineral nutrients on growth, composition and yield of cassava. Ph.D. thesis. Ithaca, N.Y. Cornell University.

Office of Agricultural Economics. 2018. Agricultural statistics of Thailand 2018. Ministry of Agriculture and Cooperatives, Bangkok.

Ogawa, K., Phetchawee, S., Suriyapan, O. 1975. The study on Fertility of Upland Soil in Thailand. Department of Agriculture, Ministry of Agriculture and Cooperative, Bangkok, Thailand.

Promma, J., Anusontpornperm, S., Thanachit, S., Kheoruenromne, I., Petprapai, P. 2012. Effect of type and rate of limes on cassava grown on Yasothon Soil. Khon Kaen Agr. J. 40: 19–26.

Riyaphan, S., Thanachit, S., Anusontpornperm, S., Suddhiprakarn, A., Petprapai, P. 2010. Alleviation of plough pan problem for growing cassava. Khon Kaen Agr. J. 38: 191–204.

Schulte, E.E. 2004. Soil and applied magnesium, A2425. In*:* Understanding Plant Nutrient. University of Wisconsin-Madison Coop, U.S.

Senbayram, M., Gransee, A., Wahle, V., Thiel, H. 2015. Role of magnesium fertilizers in agriculture: Plant-soil continuum. Crop Pasture Sci. 66: 1219–1229. doi.org/10.1071/CP15104

Wongbumru, W., Thanachit, S., Anusontpornperm, S., Wisawapipat, W. 2016. Response of cassava Huay Bong 80 variety to rates of chemical fertilizer in Yasothon soil series. Khon Kaen Agr. J. 44: 585–594.