

Effect of diatomite on yield and nutrient uptake of cassava planted in Yasothon soil series

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ABSTRACT: Cassava in northeast Thailand is commonly planted in low fertility, coarse-textured soils, resulting in unsatisfactory yields. Soil amendments can be used to enhance chemical fertilizer efficiency and subsequently increase the yield of cassava. This study was conducted on the Yasothon soil series in a farmer field, Nakhon Ratchasima province with the aim at investigating the impact of diatomite on cassava yield, primary plant nutrient uptake and some soil properties. The experiment was arranged in a randomized complete block design with four replications. Five treatments comprised: 0, 1.25, 2.5, 3.75 and 5 t/ha of diatomite addition. The cassava, Huay Bong 80 variety was a tested plant and harvested at 10-month-old. The application of 2.5 t/ha diatomite significantly promoted the highest fresh tuber yield (36.26 t/ha) and starch yield (10.35 t/ha) which were 35.5% and 41.6% greater than that obtained from the control treatment. Overall, cassava took up K in the highest amount, followed closely by N while P was taken up in far lower quantity. Over the control, all rates of diatomite applied significantly escalated the uptake of N, P and K in almost all plant parts of cassava and the whole plant. Furthermore, the addition of diatomite at all rates decreased soil bulk density, and increased pH, available P and K of the topsoil in a significant manner. Therefore, diatomite has the potential for use as a soil amendment to improve cassava yield and soil properties; however, longer-term field trials should be undertaken further to investigate its cumulative effects.

Keywords: diatomite; soil amendment; Yasothon soil series; cassava; nutrient uptake

Introduction

Cassava (*Manihot esculenta* L. Crantz) is one of important economic crops in Thailand. Cassava is a carbohydrate-rich crop that has a wide range of uses such as food for human consumption, animal feeds, fuel in the form of ethanol, alcohol, citric acid, clothing, medicines, paper, and chemicals. In Thailand, cassava exported products ranked fourth behind rice, rubber, and fruits (Office of Agricultural Economics, 2022). Cassava is planted most extensively in northeast Thailand, accounting for 941,484 ha with the total yield of 3 million tons where Nakhon Ratchasima province has the largest growing area of the country with planting area of 237,109 ha and total yield of 741,774 ton (Office of Agricultural Economics, 2022). Cassava production in this region is mostly in upland coarse-textured soils, classified as Ultisols; however, these soils such as Yasothon, Warin, Satuk Korat soil series etc., were not the most suitable for planting cassava (Sunsangaroen et al., 2014). Major constraints of soils in cassava production areas comprised coarse texture nature, weak soil structure, low fertility status, low organic matter content, low cation exchange capacity (CEC), and low water holding capacity. After having been used for growing

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Received: date; July 18, 2024 Revised: date; November 18, 2024

Accepted: date; November 18, 2024 Published: date; April 2, 2025

this plant repeatedly for a long period of time without proper soil improvement coupled with the loss of topsoil through water erosion, the productivity of these soils has mostly been diminished rather rapidly (Anusontpornperm et al., 2009; Boonrawd et al., 2021).

Attempts have been made to improve soil productivity and subsequent increase of cassava yield in coarse-textured soils by using inorganic soil amendments such as ground limestone (Lunlio et al., 2017; Tanawong et al., 2023), dolomite (Uppapanpongchai et al., 2017; Pradit et al., 2017), gypsum (Riyaphan et al., 2010; Kaewkamthong et al., 2014), bentonite (Leitch et al., 2023; Ketkhao et al., 2024), perlite (Surin et al., 2013; Chuensombat et al., 2021) etc. The positive effects of these inorganic soil amendments on cassava yield and soil improvement were observed to some different degrees, depending upon soil types and other environmental conditions. Diatomite, a naturally occurring, soft, siliceous sedimentary rock (Dobrosielska et al., 2022) with a source in Thailand located in Lampang province (Department of Mineral Resources, 2022), is one of inorganic amendments but has rarely been tested in cassava field. It is very finely porous, very low in density, and essentially chemically inert in most liquids and gases (USGS, 2024). This rock is well known to contain up to 80–90% voids (Khraisheh et al., 2004) with large surface area of 50–200 m²/g (Wu et al., 2005); thus, it has a potential to be used for improving soil physical properties. In laboratory study, diatomite application at different rates, 0%, 10%, 20%, and 30% (v/v), in soils with different textures significantly enhanced soil mechanical properties and reduced soil compactibility and the effectiveness of diatomite on liquid limit and plastic limit was more pronounced in soils with low clay content (Aksakal et al., 2013). Qu and Zhao (2016) investigated the use of diatomite to improve silt, silt loam and silty-clay loam soils. It was shown that diatomite lowered the maximum dry bulk density (MBD) of these soils and the optimum moisture content was increased with increasing rates of diatomite (0%, 10%, 20%, and 30%). In Thailand, diatomite was only ever tested as a soil amendment in maize planted in Warin soil series. The application of diatomite at the rate of 5 t/ha promoted the highest maize seed, stover and 100-seed dry weight. Diatomite also increased the uptake of N in seed, N and K in stover and, with increasing rates of diatomite, reduced bulk density of the topsoil while the rate of 5 t/ha increasing total N, available P and K over the control in the postharvest soil (Obklin et al., 2022). Therefore, this field study was undertaken to objectively investigate the effect of diatomite used as a soil amendment on improving some properties of Yasothon soil series and subsequent cassava's yield and the uptake of primary plant nutrients. Results obtained from this study should potentially be giving some knowledge about using diatomite to amend this sandy, low fertility soil of which cassava is commonly cultivated.

Materials and Methods

Site description and soil properties prior to conducting the experiment

A field trial was conducted in a farmer field at Ban Supplu Noi, Huay Bong district, Nakhon Ratchasima province, northeast Thailand (15° 8'0.57"N 101°45'12.69"E). A soil representing the experimental area was Yasothon soil series, classified as sandy, siliceous, isohyperthermic, Typic Paleustults. This soil was derived from local alluvium over residuum of conglomeratic sandstone with 3% sloping surface. Properties of the soil (0-30 and 30-60 cm) prior to conducting the experiment are presented in **Table 1**. This soil had loamy sand texture throughout 0-60 cm. Soil pH extracted with 1:1 water was moderately acid (pH 5.74) in the top layer to strongly acid (pH 5.07) in the layer underneath. The top layer contained very low amounts of organic matter, total N, available P and K, and extractable

Ca with moderately extractable Mg content while the organic matter and these nutrients in the underlying layer were lower than that in the overlying layer. This soil had low ability to retain plant nutrients as shown by its very low CEC in both layers.

Experimental design

The experiment was arranged in a randomized complete block design with 4 replications. There were 5 treatments, comprising the application of diatomite at the rates of 0, 1.25, 2.5, 3.75 and 5 t/ha. Diatomite was sourced from Mae Tha mining site, Lampang province. The properties of diatomite are shown in **Table 2**. This material is very strongly acid (pH 4.66) with rather high CEC. It is composed of Ca, Mg, Si and micronutrients to some degree.

Specific rates of diatomite were uniformly spread out onto the designed plots, and then incorporated into the soils using a 3-disc plough with 28-inch diameter disc which ploughed into 40-45 cm depth (deep tillage). The experimental area was left for two weeks, then loosened the topsoil by using a 7-disc plough before making ridges across the slope with a space of 1.2 m between ridges right afterword. Cassava, Huay Bong 80 variety was planted with an 80-cm spacing between plants. Chemical fertilizer, urea, diammonium phosphate and potassium chloride, was applied at the rate of 100:50:100 kg/ha of N:P₂O₅:K₂O as recommended for upland, light-textured Ultisols in the northeast by Sittibusaya (1996). The fertilization was done by placing fertilizer into a hole dug on the top of ridges in the middle between 2 plants and buried with the topsoil when the plant was 2-months of age. Weed control by using hand hoes and herbicides was done as necessary. The experiment was undertaken under rainfed conditions.

Plant data and sample collection

Cassava was harvested at 10 months of age. Plant components such as fresh tuber yield and aboveground fresh weight (stem base, stem, and leaf plus branch) were recorded at the time of harvest. Starch content was determined using 5 kg of fresh tuberous roots which were then weighed in the air before weighing in water, and the content was read from a Riemann scale balance according to Bainbridge et al. (1996). This starch content together with fresh tuber yield was used for the calculation of starch yield. Four different plant parts (tuber, stem base, stem, and leaf plus branch) from each plot were sampled and weighed separately, and a known-amount of samples was collected from the field for dry weight measurements and the analysis of N, P and K concentration in each plant part. The concentration of these nutrients in plant tissues and plant dry weight were then used for the calculation of plant nutrient uptake. Soil samples, so-called post-harvested soil, of each plot was taken from 0-30 cm depth during the harvesting time for the investigation of some soil properties as affected by a single application of diatomite.

Statistical analysis

The standard analysis of variance was performed for statistical analysis of data collected in the study. The significance of treatments was determined using the F-test appropriate to the general linear model as described by Gomez and Gomez (1984). The significance of the difference between the means of the treatments was determined at the 0.05 probability level ($p \leq 0.05$) using Duncan multiple range test (DMRT). Coefficient of variability (CV) was used to analyze the data (SAS Institute 2004). The statistical software used in this study was SPSS program version 21.0 (SPSS Inc., Chicago, IL).

Table 1 Soil texture and soil chemical properties prior to conducting the experiment

Soil property	Topsoil (0-30 cm)	Subsoil (30-60 cm)
Texture ¹	Loamy sand	Loamy sand
pH _w ² (1:1 H ₂ O)	5.74	5.07
Organic matter ³ (g/kg)	3.46	3.13
Cation exchange capacity, CEC ⁴ (cmol _c /kg)	2.00	2.30
Total N ⁵ (g/kg)	0.16	0.16
Available P ⁶ (mg/kg)	3.22	2.03
Available K ⁷ (mg/kg)	14.1	15.1
Extractable Ca ⁷ (cmol _c /kg)	0.66	1.05
Extractable Mg ⁷ (cmol _c /kg)	2.32	0.39
Extractable Na ⁷ (cmol _c /kg)	0.41	0.26

¹Texture measured by pipette method (Gee and Bauder, 1986), ²pH (1 : 1 H₂O) analyzed by pH meter (National Soil Survey Center, 1996), ³organic matter estimated by Walkley and Black titration (Walkley and Black, 1934), ⁴CEC measured by saturating the exchange site and displacing by 1 M NH₄OAc at pH 7.0 (Chapman, 1965); ⁵total N measured by Kjeldahl method (Jackson, 1965), ⁶available P analyzed by Bray II extraction (Bray and Kurtz, 1945), ⁷available K, extractable Ca, Mg and Na extracted with 1 M NH₄OAc at pH 7.0 and analyzed by atomic absorption spectrophotometry (AAS) (Thomas, 1982).

Table 2 Properties of diatomite used the experiment

Property	Diatomite	Property	Diatomite
pH ¹ (1:5H ₂ O)	4.66	Total Ca ⁶ (g/kg)	1.82
Cation exchange capacity ² (cmol _c /kg)	7.75	Total Mg ⁶ (g/kg)	1.04
Organic matter ³ (g/kg)	3.09	Total S ⁷ (g/kg)	0.04
Total N ⁴ (g/kg)	0.07	Total Fe ⁸ (mg/kg)	77,272
Total P ⁵ (g/kg)	0.76	Total Mn ⁸ (mg/kg)	211.3
Total K ⁶ (g/kg)	1.53	Total Zn ⁸ (mg/kg)	26.8
		Total Cu ⁸ (mg/kg)	29.2

¹pH = 1:5 H₂O analyzed by pH meter (National Soil Survey Center, 1996), ²CEC = saturating the exchange site and displacing by 1 M NH₄OAc at pH 7.0 (Chapman, 1965), ³Organic matter = Walkley and Black titration (Walkley and Black., 1934), ⁴Total N = Kjeldahl method (Jackson, 1965), ⁵Total P = Vanado-molybyyellow method (Westerman *et al.*, 1990), ⁶Total K, Ca, and Mg = Digestion in acid mixture (HNO₃-Se-HClO₄) and analyzed by AAS (Bardsley and Lancaster, 1965; Westerman, 1990), ⁷Total S = turbidimetry with BaSO₄ and determined using spectrophotometry with a 450 nm wavelength (Bardsley and Lancaster, 1965), ⁸Total Fe, Mn, Zn, Cu = Digestion in acid mixture (HNO₃-HClO₄) and analyzed by AAS (Johnson and Ulrich, 1959; Westerman, 1990).

Results

Effect of diatomite on cassava's yield and aboveground biomass

Using diatomite as a soil amendment in Yasothon soil series had a clear effect on fresh tuber yield of cassava. The application of diatomite at the rate of 2.5 t/ha significantly promoted the highest fresh tuber yield of 36.26 t/ha but with no statistical difference to that of 3.75 t/ha (34.16 t/ha) and 5 t/ha (34.58 t/ha). However, the addition of diatomite at the rate of 1.25 t/ha was not sufficient to increase this yield over the control with no addition of this inorganic soil amendment with the respective 29.08 and 26.76 t/ha of fresh tuber yield obtained (**Figure 1A**).

Cassava planted in diatomite-amended plots statistically did not give any higher starch content than that in the non-amended plot with the content ranging between 27.3-29.4%. However, with no statistical difference among treatments, it seems that the starch content augmented with increasing rates of diatomite (**Figure 1B**). In the case of starch yield, the trend was similar to that of fresh tuber yield. Amending the soil with 2.5 t/ha diatomite still significantly stimulated the highest starch yield of 10.35 t/ha whilst the amounts of 9.88 and 10.15 t/ha were obtained from the plots amended with 3.75 and 5 t/ha, respectively, but this starch yield was not statistically different among these 3 treatments. Again, the addition of diatomite at the rate of 1.25 t/ha did not boost the starch yield over the control with the starch yield being as low as 7.98 and 7.31 t/ha, respectively (**Figure 1C**).

For aboveground growth, a slightly different response of cassava to diatomite addition was observed. It was clear that diatomite had a positive impact on aboveground biomass. The significantly greatest aboveground biomass of 10.12 t/ha was detected from the plot amended with 1.25 t/ha diatomite but this amount was not statistically different from that obtained from the other diatomite-amended plots (8.48-9.26 t/ha). Growing cassava without using diatomite to amend the soil, the top growth of cassava was the poorest with the value of 7.32 t/ha (**Figure 1D**).

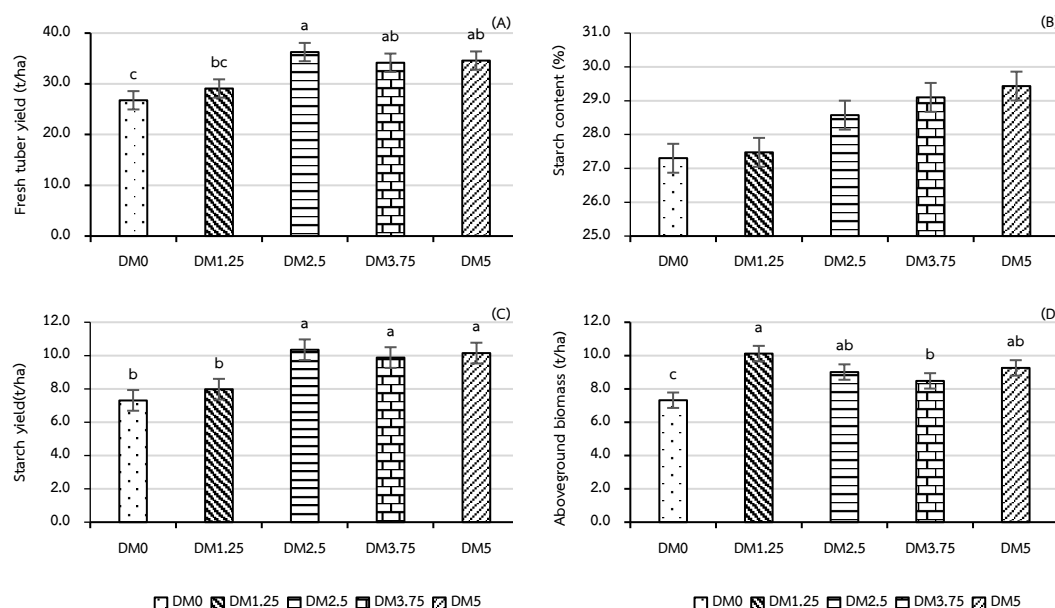


Figure 1 Effect of diatomite on fresh tuber yield (A), starch content (B), starch yield (C) and aboveground biomass (D), where different lowercase letters above bars are significantly ($p \leq 0.05$) different, DM0 = diatomite 0 t/ha; DM1.25 = diatomite 1.25 t/ha; DM2.5 = diatomite 2.5 t/ha; DM3.75 = diatomite 3.75 t/ha; DM5 = diatomite 5 t/ha.

Effect of diatomite on primary plant nutrient uptake

The use of diatomite as a soil amendment had, to different degrees, the impact on the uptake of NPK in different plant parts of cassava and in the whole plant (**Table 3**). Overall, cassava took up K in the highest amount, followed closely by N with P being taken up the least and far lower than K and N. Nitrogen stored in tuber and leaf plus branch in the similarly highest amount. It was also the case for P, but the highest K storage was in tuber and the quantity was much higher than that in the other parts of cassava.

The addition of diatomite at almost all rates significantly induced greater N uptake in tuber, stem base, stem, leaf plus branch and the whole plant than did the control with no diatomite addition, except for the rate of 5 t/ha in the case of N uptake in tuber. Phosphorus and K taken up in all plant parts of cassava and in the whole plant significantly increased with increasing rates of diatomite applied in a similar manner with only in leaf plus branch that the rate of 1.25 t/ha statistically raised the highest uptake of both nutrients.

Table 3 Effect of diatomite on N, P and K uptake (kg/ha) in different plant parts of cassava

Treatment	Tuber	Stem base	Stem	Leaf plus branch	Whole plant
Nitrogen uptake					
DM0	31.56±2.25 ^c	6.07±0.92 ^b	3.54±0.21 ^c	21.94±1.36 ^c	63.10±3.27 ^c
DM1.25	39.94±2.42 ^{ab}	9.68±0.25 ^a	6.19±0.10 ^b	32.35±1.44 ^a	85.16±3.06 ^a
DM2.5	40.03±0.95 ^a	10.10±1.64 ^a	7.14±0.49 ^a	28.10±2.01 ^b	85.38±1.96 ^a
DM3.75	34.93±3.34 ^b	9.37±0.25 ^a	7.06±0.69 ^a	29.52±2.94 ^b	80.87±5.91 ^{ab}
DM5	29.19±1.22 ^c	10.06±0.42 ^a	7.54±0.19 ^a	30.77±0.26 ^{ab}	77.56±1.68 ^b
F-test	**	**	**	**	**
Mean±SD	34.53±4.40	9.05±1.74	6.29±1.53	28.54±4.02	78.41±8.96
C.V. (%)	6.0	8.9	6.7	6.0	4.0
Phosphorus uptake					
DM0	1.92±0.05 ^e	0.67±0.18 ^b	0.26±0.02 ^b	1.31±0.43 ^c	4.16±0.58 ^d
DM1.25	2.97±0.07 ^d	0.73±0.03 ^b	0.57±0.01 ^a	2.04±0.24 ^a	6.31±0.27 ^c
DM2.5	3.56±0.09 ^c	0.82±0.13 ^b	0.58±0.04 ^a	1.60±0.12 ^{bc}	6.57±0.15 ^c
DM3.75	5.35±0.59 ^b	0.81±0.04 ^b	0.54±0.05 ^a	1.68±0.17 ^b	8.38±0.39 ^b
DM5	6.39±0.48 ^a	1.02±0.07 ^a	0.57±0.06 ^a	1.72±0.01 ^{ab}	9.70±0.55 ^a
F-test	**	**	**	*	**
Mean±SD	4.04±1.69	0.81±0.16	0.50±0.13	1.67±0.32	7.02±1.98
C.V. (%)	9.0	13.0	8.9	13.4	6.5
Potassium uptake					
DM0	57.48±1.41 ^c	5.20±0.95 ^c	1.32±0.07 ^e	5.98±0.37 ^b	69.98±2.13 ^c
DM1.25	74.83±1.65 ^b	5.74±0.32 ^{bc}	3.22±0.05 ^d	7.95±0.96 ^a	91.75±2.26 ^b
DM2.5	96.61±2.28 ^a	7.30±1.18 ^a	4.93±0.34 ^c	6.88±0.49 ^b	115.72±2.62 ^a
DM3.75	98.05±17.42 ^a	6.58±0.30 ^{ab}	6.26±0.61 ^b	6.96±0.69 ^b	117.84±17.09 ^a
DM5	97.95±7.27 ^a	7.47±0.31 ^a	8.34±0.92 ^a	6.98±0.06 ^b	120.74±7.37 ^a
F-test	**	**	**	*	**
Mean±SD	84.98±18.40	6.46±1.10	4.81±2.53	6.95±0.83	103.20±21.45
C.V. (%)	10.9	11.3	10.1	8.9	8.9

C.V. = coefficient of variation; DM0 = diatomite 0 t/ha; DM1.25 = diatomite 1.25 t/ha; DM2.5 = diatomite 2.5 t/ha; DM3.75 = diatomite 3.75 t/ha; DM5 = diatomite 5 t/ha.

*, ** significantly different at 0.05 and 0.01 probability levels, respectively; mean±SD superscripted with different lowercase letters grouped within the same plant part indicate significant difference of treatments, according to Duncan's multiple range test at $p \leq 0.05$.

Effect of diatomite on properties of post-harvested soil

As aforementioned, soil samples were collected from the topsoil (0-30 cm) during the harvesting period which is so-called the post-harvested soil. Diatomite applied at all rates significantly decreased bulk density of the topsoil after growing cassava for one growing season. The soil bulk density was the highest (1.64 Mg/m^3) in the non-amended plot where the significantly lower bulk density, varying between 1.46 - 1.59 Mg/m^3 were observed in all diatomite-amended plots (**Figure 2**).

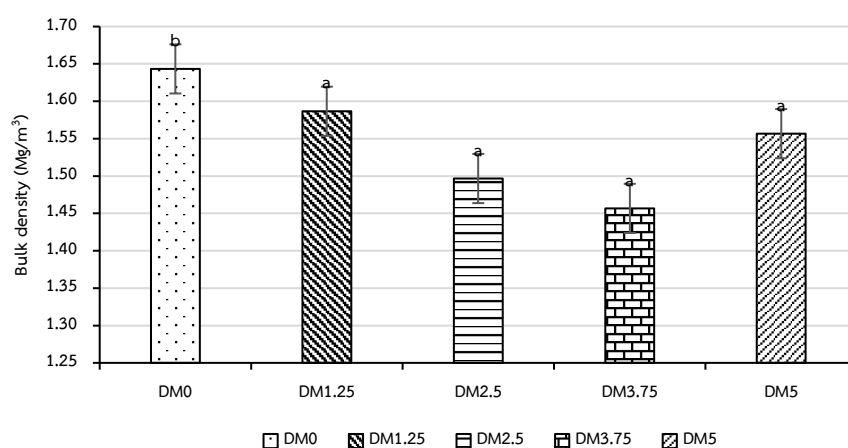


Figure 2 Effect of diatomite on bulk density of post-harvested topsoil (0-30 cm), where different lowercase letters above bars are significantly ($p \leq 0.05$) different, DM0 = diatomite 0 t/ha; DM1.25 = diatomite 1.25 t/ha; DM2.5 = diatomite 2.5 t/ha; DM3.75 = diatomite 3.75 t/ha; DM5 = diatomite 5 t/ha.

The effect of diatomite on some soil chemical properties is shown in **Table 4**. Diatomite has an acidic nature, but it significantly increased pH of the topsoil with the pH increasing with increasing rates of this material. It had no clear impact on the content of organic matter nor total N which the latter statistically differed among treatments but irrelevant to the rates of diatomite applied. Available P content build-up was rather clear in the treatments with diatomite involved (9.80 - 15.29 mg/kg) with the control without adding diatomite containing the significantly lowest amount of 3.71 mg/kg . The quantity of available K only increased over the control when diatomite was applied at the rates of 3.75 and 5 t/ha with the respective values of 16.93 and 20.87 mg/kg .

Table 4 Effect of diatomite on some soil chemical properties of post-harvested topsoil (0-30 cm)

Treatment	pH	Organic matter	Total N	Avail. P	Avail. K
	(H ₂ O 1:1)	(g/kg)	(g/kg)	(g/kg)	(g/kg)
DM0	4.91±0.08 ^c	4.70±0.61	0.28±0.00 ^c	3.71±0.95 ^b	12.43±1.00 ^c
DM1.25	5.24±0.06 ^b	5.04±0.00	0.21±0.00 ^d	12.41±1.15 ^a	14.38±1.56 ^{bc}
DM2.5	5.26±0.06 ^b	5.12±0.47	0.21±0.00 ^d	14.20±1.00 ^a	12.84±0.90 ^c
DM3.75	5.31±0.00 ^{ab}	4.78±0.05	0.32±0.03 ^b	15.29±5.59 ^a	16.93±1.07 ^b
DM5	5.37±0.09 ^a	5.22±0.14	0.39±0.03 ^a	9.80±4.21 ^a	20.87±5.17 ^a
F-test	**	ns	**	**	**
Mean±SD	5.22±0.18	4.97±0.37	0.28±0.07	11.03±5.10	15.49±3.91
C.V. (%)	1.36	6.76	0.00	30.98	13.29

C.V. = coefficient of variation; DM0 = diatomite 0 t/ha; DM1.25 = diatomite 1.25 t/ha; DM2.5 = diatomite 2.5 t/ha; DM3.75 = diatomite 3.75 t/ha; DM5 = diatomite 5 t/ha.

ns = not significant; ** significantly different at 0.01 probability level; mean±SD superscripted with different lowercase letters grouped within the same soil property indicate significant difference of treatments, according to Duncan's multiple range test at $p \leq 0.05$.

Discussion

Effect of diatomite on cassava yields

Yosothon soil series is one of major soils commonly used for cassava cultivation in the northeast. This rather sandy soil has low fertility level (**Table 1**) with low ability to retain plant nutrients (Anusontpornperm et al., 2009; Boonrawd et al., 2021). As vastly reported (Riyaphan et al., 2010; Kaewkamthong et al., 2014; Lulio et al., 2017; Ruenchan et al., 2018; Klongtham et al., 2020; Chatkaewvorakul et al., 2022), cassava planted in this soil without soil improvement by using soil amendments generally gave unsatisfactory yield even though chemical fertilizers were properly applied. It was the case in this current study as the lowest fresh tuber yield, starch yield and aboveground biomass were observed in the control plot without diatomite addition but received 100:50:100 kg/ha of N:P₂O:K₂O. The addition of diatomite at the rate of 2.5 t/ha positively increased fresh tuber yield by 35.5% over the control. The addition of diatomite greater than this rate also boosted the yields of cassava but the amounts were not superior to that of 2.5 t/ha which means these two rates, 3.75 and 5 t/ha of diatomite, are not economically practical. However, the addition of diatomite at the rate of 1.25 t/ha was deemed insufficient to improve in this soil and subsequently increase the yields because the yields, both fresh tuber and starch, were not statistically different from that obtained from the control plot, 29.08 t/ha compared to 26.76 t/ha. This result quite coincided with the study on using diatomite to improve Warin soil series for growing maize (Obklin et al., 2022) of which only the addition of this material at the rate of 5 t/ha increased the yield of maize over the control whereas applying at the rates of 1.25 and 2.5 t/ha showed no clear impact on increasing maize's yield. It was also consistent with Angin et al. (2011) who found that diatomite improved soil physical properties and, in turn, increased yield of strawberry improvement. In addition, Escobar et al. (2014) reported that diatomite enhanced well with chemical fertilizer, resulting in the increase of sweet corn's yield over sole application of the chemical fertilizer. In the case of cassava

yield increase in this study, diatomite plays a part in lowering soil bulk density (**Figure 2**) which should favour root growth and tuberization and partly this material may have diminished the loss of nutrients via leaching as it has rather high CEC which should be effective in this sandy soil that has very low CEC, notably when applied at the sufficiently high rate. Calcium and Mg in diatomite might also involve in the increase of yield as studies on cassava grown in these types of soils showed a positive response to these two nutrients (Somngam et al., 2018; Charoenphon et al., 2019). Additionally, it might also be the case for micronutrients in diatomite.

Effect of diatomite on primary nutrient uptake

The uptake of N, P and K in the whole plant cross all treatments varied in the ranges of 63.10-85.38 kg/ha, 4.16-9.70 kg/ha and 69.98-120.74 kg/ha, respectively (**Table 3**), representing the approximate proportion of 11:1:14 which was not in good agreement with Imas and John (2013), Chaem-ngern et al. (2020) and Prombut et al. (2022) as they all reported greater P uptake with variations of N to K proportion but was consistent with a study of Leitch et al. (2023) in Warin soil series which P was taken up in a very low amount even when cassava received 100 kg/ha of P_2O_5 . The high proportions of N and K uptake in this study might be because diatomite that has rather high CEC (**Table 2**) eased the loss of some cationic nutrients such as NH_4^+ and K^+ through leaching, allowing cassava to take up these two nutrients more effectively. In contrast, this Yasothon soil series has a red colour which indicates the soil to have more Fe and possibly Al oxides, resulting in its having rather high P fixation (Ratanavirakul et al., 2022). This, coupled with low pH nature of diatomite (pH 4.66), might be responsible for low P availability, causing cassava to take up less P.

Effect of diatomite on soil properties

The application of diatomite at all rates evidently lowered bulk density of the topsoil (**Figure 2**). This was because this inorganic amendment contains a very high percentage of voids (Khraisheh et al., 2004) and it was widely reported that this material reduced soil compactibility, especially in soils with low clay content (Aksakal *et al.*, 2013). The positive impact on soil bulk density observed in this study as soil bulk density decreased with increasing rates of diatomite was consistent with the studies of Qu and Zhao (2016) in silt, silt loam and silty-clay loam soils and Obklin et al. (2022) in Warin soil series with a loamy sand topsoil.

Coincidentally, diatomite increased topsoil pH slightly over the control despite the material having low pH. This might be down to some bases in diatomite that released to the soil and subsequently replaced or reacted with hydronium ions in soil solution. Organic matter content was not affected by diatomite addition due to its having very low amount of organic carbon (3.09 g/kg). This was true in this tropical sandy soil where organic carbon can be decomposed so swiftly (Sanchez, 2019) even when inorganic and organic amendments have been applied for several years (Klongtham et al., 2020; Chatkaewvorakul et al., 2022). However, the increase of P and K availability in diatomite-amended plots agreed with several reports. Obklin et al. (2022) showed the impact of diatomite on increasing available P and K contents in Warin soil series. Escobar et al. (2014) also showed that the soil treated with diatomite had greater nutrient storage than the non-treated soil. This is because diatomite has high water adsorption capacity (Murer et al., 2000), is composed of high total porosity up to 70% (Zahajská et al., 2020) and small particles with low density (Hassan et al., 1999) and high specific surface areas (Gao et al., 2005) in addition with rather high CEC (**Table 2**). These properties should contribute to the holding of some plant nutrients within the rooting zone, particularly when applied at a slightly sufficiently high rate.

Conclusions

Diatomite used as a soil amendment can improve cassava's yield, primary plant nutrient uptake and some properties of Yasothon soil series. The addition of 2.5 t/ha of diatomite was the best rate as it promoted the highest fresh tuber yield and starch yield of cassava, Huay Bong 80 variety. Any higher rates also gave similarly high yield but were economically impractical. The addition at the rate of 1.25 t/ha was deemed insufficient to improve cassava's yields over no diatomite application. All rates of diatomite increased the uptake of N, P and K in almost all plant parts and in the whole plant. Diatomite applied at all rates evidently decreased bulk density and increased pH, available P and K of the topsoil, amid rather high rates for the latter nutrient. This inorganic amendment has the potential to improve soil properties and subsequent increase of cassava yield; however, a longer-term field trial should be carried out to investigate a cumulative effect of diatomite on cassava performance and soil properties in this soil and other different soil types.

Acknowledgements

This research was funded by the grant FF(KU5.65) from the Kasetsart University Research and Development Institute (KURDI). The Siam Cement Public Company Limited and the Thai Central Chemical Public Company Limited provided respective the diatomite and the NPK chemical fertilizers.

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