The impacts of tillage, soil conditioners, and chemical fertilizer on yield of cassava in Yasothon Soil Series (Typic Paleustult), relationship between nutrient concentration and cassava yield components, and soil property

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ABSTRACT: A study was conducted in a farmer field at Ban Supplu Noi, Huay Bong subdistrict, Dan Khun Thot district, Nakon Ratchasima. Cassava, Huay Bong 80 variety, was planted in Yasothon soil series classified as a Typic Paleustult. Split-split plot in RCBD was employed with four replications. Main plot consisted of normal (N) and deep tillage (D). Subplot contained 11 treatments, T1: no soil conditioner applied, and applying respective rates of 625 and 1,250 kg/ha of soil conditioners such as bentonite (T2 and T3), perlite (T4 and T5), gypsum (T6 and T7), dolomite (T8 and T9), and ground limestone (T10 and T11). Sub-subplot was performed with two rates of 15-15-15 chemical fertilizer; 312.5 (L) and 625 (H) kg/ha. Soil representing the experimental area was classified as a Typic Paleustult. Cassava was harvested at 10-month of age. Different plant parts of cassava were sampled during the harvesting time for the analysis of nutrient concentration. Results showed that deep tillage highly significantly promoted higher fresh tuber yield (FTY) of 28.62 t/ha and starch yield (STY) of 7.77 t/ha than did normal tillage (25.61 and 6.93 t/ha, respectively) but had no different effects on starch content (STC) and aboveground biomass (ABG). The application of dolomite (T8) significantly gave the highest FTY, STY and ABG of 31.68, 8.65 and 10.97 t/ha, respectively. Cassava did not respond to rates of chemical fertilizer differently. However, there were some interactions between tillage and chemical fertilizer that affected cassava yield components. There were positive correlations between plant nutrient concentrations, especially macronutrient in stem, with FTY and ABG. Both rates of dolomite (T8 and T9) and ground limestone (T10 and T11) induced higher soil pH than did other soil conditioners and the control. Furthermore, the application of some soil conditioners contributed higher available P, K and Mg contents remained in the soil after growing cassava for one crop.

Keywords: Plough Pan, Tillage Practice, Soil Conditioner, Cassava, Northeast Thailand

Introduction

Cassava (*Manihot esculenta* Crantz.) is considered one of the most important economic crops in Thailand of which the country is the leading cassava exporter of the world. Planting area of cassava in Thailand in 2015 was around 1.49 million ha. A major cassava planting area is in the north-east, accounting for approximately 0.78 million ha. However, the average yield of cassava in this region is lower than in other regions (Office of Agricultural Economics, 2016). Most cassava growing soils in the northeast have sandy loam to coarser texture, possessing low agricultural potential, low fertility, weak structure, moderate to excessive drainage and high rate of leaching (Howeler, 1981; Ratana-waraha et al., 1997; Anusontpornperm et al., 2009). Plough pan is one of major problems in these cassava growing soils in the region (Anusontpornperm et al., 2005; Kliaklom et al., 2010; Meewassana et al., 2010). Hamza and Anderson (2002) found that deep ripping alone increased the infiltration rate in the first three years but the effect did not last into the fourth year. There are some reports showing that subsoiling by using ripper gave significantly higher fresh tuber yield than did the other without using ripper (18.25 compared to 16.13 t/ha) (Riya-phan et al., 2010). Using ripper to breakdown plough pan gave fresh tuber yield of 33.94 t/ha, which was significantly higher than that of without

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rippering (28.94 t/ha) in the first year but the effect was to no avail in the following year (Suksawat et al., 2010). This indicated that the efficiency of ripper lasted only one year and is of the case according to the study of Kaewkamthong et al. (2014).

Uses of soil conditioners for improving the soils in this region have been studied (Duangpatra, 1988). For instance, ground limestone and dolomite that are rich in calcium can increase soil pH and available phosphorus (Riyaphan et al., 2010; Promma et al., 2012) and also improve soil structure, especially in reducing compaction (Duangpatra, 2013). The addition of ground limestone, dolomite and gypsum on a Yasothon soil increased fresh tuber yield of cassava, number of tuber/plant, above ground biomass, and starch content, particularly more clearly in the second year (Promma et al. 2012). As results of using ripper to breakdown plough pan that helped improve yield of cassava only in the first year, this study was undertaken with the aims at investigating the impact of tillage, soil conditioners and chemical fertilizer on yield, and correlations between nutrient concentration and yield components of cassava grown on a Typic Paleustult, which is a major cassava soils in the northeast (Anusontpornperm et al., 2009) and to examine soil properties as affected by these practices.

Materials and Methods

The experiment was carried out in a farmer field at Ban Sapplu Noi, Huay Bong subdistrict, Dan Khun Thot district, Nakon Ratchasima province during November 2012 and October 2013. The experimental site was undulating with 5% slope and elevation of 380 m above MSL. The average annual rainfall and temperature at the site were 1,306.0 mm/yr and 27.6 °C, respectively. The soil was developed on local alluvium over residuum derived from sedimentary rock mainly conglomerate and sandstone, having well-drained feature with rapid permeability and runoff. This soil was classified as a Typic Paleustult (Yasothon soil series). General soil properties are presented in **Table 1**. Properties of soil before planting, obtained from the analysis of composite sample collected from 0-30 cm from experimental plots, showed that the soil was composed of very low amounts of N (0.21 g/kg), available P (1.09 mg/kg), available K (28.5 mg/kg) and extractable Ca, Mg and K (0.94, 0.25 and 0.07 $cmol_c$/kg, respectively) with very low cation exchange capacity (0.21 $cmol_c$/kg).

Split-split plot in randomized complete block design were employed with four replications. The main plot consisted of normal tillage (N) and deep tillage (D) with the first plough using 3-disc plough operated to depths of 25-30 and 45-50 cm, respectively. Subplot contained 11 treatments; T1: no application of soil conditioner, and all the rest applying two respective rates of 625 and 1,250 kg/ha of different soil conditioners such as bentonite (T2 and T3), perlite (T4 and T5), gypsum (T6 and T7), dolomite (T8 and T9), and ground limestone (T10 and T11). Sub-subplot comprised two rates of 15-15-15 chemical fertilizer, (312.5 (L) and 625 (H) kg/ha). Cassava, Huay Bong 80 variety, was planted on ridges with a spacing of 0.8 m between plants and 1.2 m between rows and harvested at 10 months of age. Plant and soil samples were taken at the time harvest for analyses of nutrient concentration and soil properties, respectively. Site characterization of the experimental area was carried out according to standard field methods. Cassava yield, measured plant components, and soil properties were compared among treatments using the analysis of variance for statistical significance, and mean separation was done using SPSS program and Duncan's multiple range test (DMRT) with differences being tested at 0.01 and 0.05 level of significance.

Table 1 Physical and chemical properties of a Typic Paleustult (Yasothon soil series), representative soil of the experimental area.

Depth (cm)	Hor.	pH[1/] 1:1 H_2O	OM[2/] (g/kg)	Extractable base[3/] Ca	Mg	K	Na	CEC[4/]	BS[5/] (%)	BD[6/] (Mg/m^3)	Ksat[7/] (cm/hr)	Texture[8/]
				(---------$cmol_c$/kg------------)								
0-15/17	Ap	5.9	3.8	0.11	0.05	0.01	0.18	0.7	26.1	1.52	5.7	LS
15-30	Bt1	6.2	1.5	0.19	0.05	0.01	0.07	0.6	24.5	1.62	3.8	SL
30-65	Bt2	5.3	1.0	0.21	0.05	0.01	0.19	0.8	31.5	1.56	5.4	SL
65-90	Bt3	6.0	1.1	0.25	0.03	0.01	0.06	1.3	14.9	1.45	2.9	LS
90-117	Bt4	5.8	0.8	0.18	0.05	0. 01	0.22	0.8	31.7	1.55	4.0	SL
117-142	Bt5	5.7	1.0	0.08	0.06	0.01	0.15	0.8	7.0	1.51	2.2	SL
142-168	Bt6	5.8	1.2	0.03	0.08	0.01	0.19	1.1	13.6	1.45	4.6	SL
168-190	Bt7	5.5	1.0	0.05	0.08	0.01	0.28	0.8	17.3	1.53	2.2	SL
190-210+	Bt8	5.2	1.3	0.07	0.08	0.01	0.21	0.9	15.7	1.50	1.0	SL

Hor. = horizon, OM = organic matter, CEC = cation exchange capacity, BS = base saturation, BD = bulk density, Ksat = hydraulic conductivity, LS = loamy sand, SL = sandy loam

[1]pH (H_2O), [2]Walkley and Black, [3]1M NH_4OAc at pH 7.0, [4]1M NH_4OAc at pH 7.0, [5]1M NH_4OAc at pH 7.0, [6]Core method, [7]variable head method, [8]pipette method

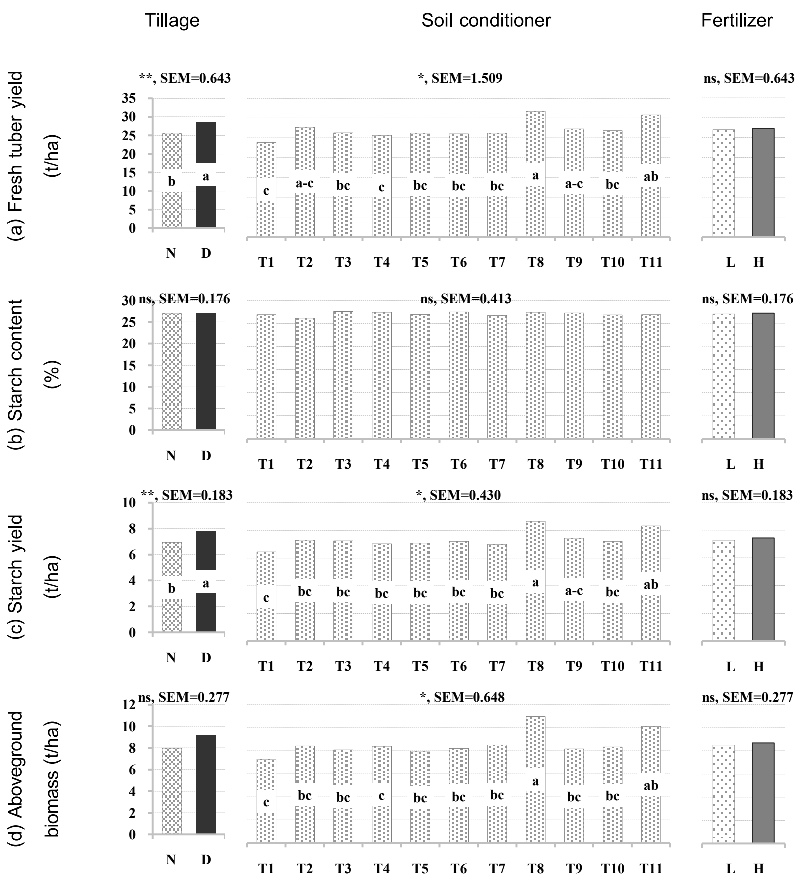
Results and discussion

Effects of tillage, soil conditioners and chemical fertilizer on cassava fresh tuber yield, starch content, starch yield and aboveground biomass

Deep tillage to the depth of 45-50 cm (D) highly significantly gave higher fresh tuber yield of 28.62 t/ha and starch yield of 7.78 t/ha than did normal tillage to the depth of 25-30 cm (N) that had both yields of 25.61 and 6.93 t/ha, respectively (**Figure 1a, c**) while there was no difference in starch content and aboveground biomass (**Figure 1b, d**). It can be stated that deep tillage that took some of subsoil, which possessed some unfavorable properties such as low soil pH and very low organic matter content, to mix with topsoil did not have adverse effect of growing plant. This operation may have helped enhance growth and subsequently results in an increase of cassava yield as dense layer directly beneath the topsoil was destroyed. In addition to that, the movement of water within soil profile would be more rapidly, resulting in reducing accumulation of water in the soil surface and subsequent runoff (Hassan et al., 2007). Although, this result is yet to be sufficiently conclusive, previous studies showed that to prevent recompaction and help re-forming the structure of tilled soil, a binding or flocculating agent (lime, gypsum or organic matter) is needed. Without such agent compaction can recur (Hamza and Anderson, 2002; 2003) sometime in the first year after tillage (Moffat and Boswell, 1996). Hall et al. (1994) reported that the effect of deep tillage on soil-water relations declines after the first year and yield increases associated with deep tillage did not persist beyond the second year of the experiment, presumably due to re-compaction.

The soil amended with dolomite at the rate of 625 kg/ha (T8) significantly gave the highest fresh tuber yield of 31.68 t/ha. This amount of yield was statistically not different from those obtained from plots amended with dolomite at doubling rate (T9), both rates of ground limestone (T10 and T11), and bentonite at the rate of 625 kg/ha that gave the yield in the range of 27.20-30.83 t/ha. It was clear that growing cassava without the use of soil conditioner gave the lowest yield of 23.82 t/ha (**Figure 1a**). Similar trends were also found in the case of starch yield and aboveground biomass (**Figure 1c, d**) that the application of dolomite at the rate of 625 kg/ha (T8) also positively showed the greatest impact. This coincides with Manrique (1987) in which the result showed a positive and significant cassava yield response to liming a strongly acid Ultisol with 6-11 t/ha lime. In addition, recent studies conducted on rather similar soils in the northeast also demonstrated better effectiveness of dolomite and ground limestone used to condition the soil for growing cassava than the others (Kanjana et al., 2012; Yimnoi et al., 2014).

It was rather surprising that different rates of chemical fertilizer added did not give any different yield components instead of the higher rate being twice higher. Although, Sittibusaya (1996), based on results of a large number of FAO-sponsored on-farm fertilizer trails, recommended almost the same amount as the higher rate (H) used in this experiment, the yield response did not come to term as expected. This might be due to the soil having been severely degraded or amounts of major plant nutrient required by cassava, Huay Bong 80 variety, being different from those varieties used in those trials. Nonetheless, there were no different effects of interactions between tillage and soil conditioner, tillage and chemical fertilizer, and soil conditioner and chemical fertilizer these yield components.



N = Normal tillage; D = Deep tillage; T1: no soil conditioner, T2 and T3: bentonite 625 and 1,250 kg/ha, T4 and T5: perlite 625 and 1,250 kg/ha, T6 and T7: gypsum 625 and 1,250 kg/ha, T8 and T9: dolomite 625 and 1,250 kg/ha, and T10 and T11: ground limestone 625 and 1,250 kg/ha, L and H = Chemical fertilizer 312.5 and 625 kg/ha; common letters on the top of bars are not significantly different; no letter on the top of bars shows no significant difference

Figure 1 Effects of tillage, soil conditioners and chemical fertilizer on cassava fresh tuber yield, starch content, starch yield and aboveground biomass

Effects of tillage, soil conditioners and chemical fertilizer on the relationships between plant nutrient concentration and cassava yield components

Pearson correlation coefficient (2-tailed) was done to establish relationships between nutrient concentration and cassava yield components (**Table 2**). Phosphorus concentration in tuber positively correlated with aboveground biomass (r = 0.20**) while Mg concentration significantly showed a negative correlation with aboveground biomass (r = -0.15*). In stem base, P concentrations had highly positive correlations with fresh tuber yield (r = 0.37**), starch yield (r = 0.36**) and aboveground biomass (r = 0.30**).

In stem, P concentrations highly positively correlated with fresh tuber yield (r = 0.27**), starch yield (r = 0.26**) and aboveground biomass (r = 0.23**). Nitrogen concentrations in this plant part also positively correlated with fresh tuber yield (r = 0.18*), starch yield (r = 0.18*) and aboveground biomass (r = 0.15*). Potassium concentrations highly significantly had positive correlations with fresh tuber yield (r = 0.22**) and starch yield (r = 0.23**). Moreover, Ca concentrations highly positively correlated with fresh tuber yield (r = 0.21**), starch yield (r = 0.22**) and had a positive correlation with aboveground biomass (r = 0.15*). There were positive correlations between Mg concentrations and fresh tuber yield (r = 0.16*) and starch yield (r = 0.16*).

In leaf and branch, there were only some micronutrients that had correlations with yield components. Manganese concentration had positive correlations with fresh tuber yield (r = 0.18*), starch yield (r = 0.19*) and aboveground biomass (r = 0.20**) while Cu concentration positively correlated with aboveground biomass (r = 0.20**).

Considering fresh tuber yield, P concentrations in stem base and stem, N, K, Ca and Mg concentrations in stem and Mn concentration in leaf and branch showed positive correlations to different degrees. This indicated that the increase of these nutrients concentration in aboveground plant part had the effect on increasing cassava fresh tuber yield. In the case of starch yield or in the other word, the quality of cassava tuber, there were P concentration in tuber, all major plant nutrients in stem including Ca and Mg, and Mn in leaf and branch that had the correlation with starch yield. This can be indicative of the plant with substantial amounts of macronutrients stored in the stem part being likely to give satisfactory starch yield. Among these correlations found in the study, P was the most common, thus management of P fertilization is vital in terms of improving yield of cassava, Huay Bong 80 variety, grown on this Typic Paleustults, of which this initial content of it available form before planting was very low (0.19-1.09 mg/kg).

Phosphorus in leaf and branch, stem and stem base usually promotes root growth and plays an important role in energy transformations and metabolic processes in plants. It is essential for photosynthesis and carbohydrate synthesis, hence important for tuberization. Cassava is found to be inefficient in P uptake though it grows well in low P soil and cassava's response to P has usually been minor (John, 2010). Improvement in quality of cassava due to increase in starch yield and decrease in cyanogenic glycoside content as a result of higher levels of P nutrition were reported by John et al. (2005). Application of P up to 100 kg/ha P_2O_5 enhanced starch yield and reduced HCN content. Moreover, significant reduction in HCN content, increasing in dry matter, starch and crude protein contents due to P fertilization (John et al., 2006).

Table 2 Correlations between nutrient concentration in various parts of cassava and cassava yield components

Concentration	Pearson's r (N=176)									
Tuber	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
FTY	0.11	0.14	-0.01	-0.08	-0.07	0.08	0.08	0.07	0.11	0.02
STC	-0.01	0.02	0.01	0.01	0.14	0.03	0.07	-0.04	-0.12	-0.06
STY	0.11	0.14	-0.01	-0.08	-0.04	0.09	0.09	0.05	0.07	0.00
ABG	0.13	0.20**	0.06	-0.13	-0.15*	0.14	0.06	0.14	0.06	0.11
Stem base	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
FTY	0.07	0.37**	-0.07	-0.03	0.05	-0.05	-0.08	0.02	-0.07	-0.03
STC	-0.12	0.03	0.08	-0.11	-0.10	-0.08	0.06	0.00	-0.02	-0.07
STY	0.03	0.36**	-0.05	-0.06	0.03	-0.06	-0.07	0.02	-0.08	-0.05
ABG	0.11	0.30**	0.00	-0.02	0.05	-0.02	0.04	0.02	-0.08	0.03
Stem	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
FTY	0.18*	0.27**	0.22**	0.21**	0.16*	0.07	0.04	-0.03	0.00	-0.06
STC	0.07	0.04	0.08	0.10	0.04	0.11	0.00	0.04	-0.03	0.00
STY	0.18*	0.26**	0.23**	0.22**	0.16*	0.09	0.04	-0.01	-0.02	-0.06
ABG	0.15*	0.23**	0.11	0.15*	0.12	0.02	0.01	-0.02	-0.02	-0.12
Leaf and branch	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
FTY	0.11	0.01	0.10	-0.01	-0.06	0.06	0.01	0.18*	-0.05	0.11
STC	0.02	0.05	0.01	0.03	0.01	0.10	0.14	0.11	0.00	0.09
STY	0.11	0.02	0.11	0.00	-0.05	0.08	0.05	0.19*	-0.03	0.13
ABG	0.12	0.10	0.09	-0.03	-0.05	0.04	0.03	0.20**	0.02	0.21**

FTY: fresh tuber yield, STC: starch content, STY: starch yield, ABG: aboveground biomass

* significant correlation, ** highly significant correlation

The other two major plant nutrients, N and K, also showed correlation between their concentration in stem and cassava yield. Nitrogen is the second nutrient, after potassium, most used by cassava (Howeler, 2002, 2014; Ayoola and Makinde, 2007) in some cases. Nitrogen generally promotes growth, improves the efficiency of photosynthesis, increases leaf area index (LAI) and increases the yield (Howeler, 2002; 2014). Large nitrogen applications can also likely to reduce the harvest index (HI), root yield and starch content while increasing the HCN content of the root (Edwards and Kang, 1978). The positive correlation found here indicated that the increase of this nutrient, especially in the stem can possibly increase fresh tuber and starch yields. This was also the case for K as shown by its concentration in stem with fresh tuber and starch yields in which this nutrient in stem besides increasing the overall yield improves dry matter, starch yield and reduces HCN content. Application of K at 100 kg/ha K_2O produced higher tuber yield with high percentage starch yield and low HCN content (Nair and Aiyer, 1986).

Effects of tillage, soil conditioners and chemical fertilizer on soil chemical property

The use of dolomite at the rate of 1,250 kg/ha (T9) to condition the soil highly significantly induced the highest soil pH of 6.34 (**Figure 2a**). The values were also higher than that of the plot amended with the lower rate of the same material. Ground limestone also lifted soil pH when compared to other soil conditioners such as bentonite, perlite and gypsum and the control with no application of soil conditioner. This is because lime ($CaCO_3$) was effective in raising soil pH (Liu and Hue, 2011). Dolomite and ground limestone had the effect on reducing soil acidity level in coarse-textured soil and contained high amount of bases such as Ca and Mg, which can serve to reduce soil acidity (Redly and Utkaeva, 2009) whereas bentonite, perlite and gypsum are not lime material used for reducing soil acidity. The results of this study agree with those obtained by Makarim et al. (1989) and Cassel et al. (1990) in West Sumatra. These results revealed that large quantities of lime and commercial fertilizers were needed for rapid reclamation of acid, infertile soil. In addition, lime provides Ca^{2+} and generates OH^- ions that neutralize the acidity, thus raising the pH (Peregrina et al., 2006).

All practices had no effect on soil organic matter content which the amounts (4.08 and 4.33 g/hg) remained in the soil were still very low (**Figure 2b**). The amounts of soil organic matter as affected by soil conditioners applied were in the ranges of 3.78-4.56 g/kg. The soil amended with bentonite at the rate of 625 kg/ha (T2) significantly gave the highest available phosphorus of 10.23 followed by 9.97 mg/kg being from the plot amended with the same soil conditioner at doubling rate (T3). It can be noticed that the lowest amounts of available phosphorus left in the topsoil were in the control plot with no application of soil conditioner. Normal placement of bentonite at the rate of 1,250 kg/ha (NT2) significantly gave the highest available phosphorus of 10.54 mg/kg left in the topsoil (**Figure 2c**). Different depths of tillage with no addition of soil conditioner (NT1 and DT1) evidently resulted in the lowest amounts (7.26 and 6.64 mg/kg) of available phosphorus remained in the soil.

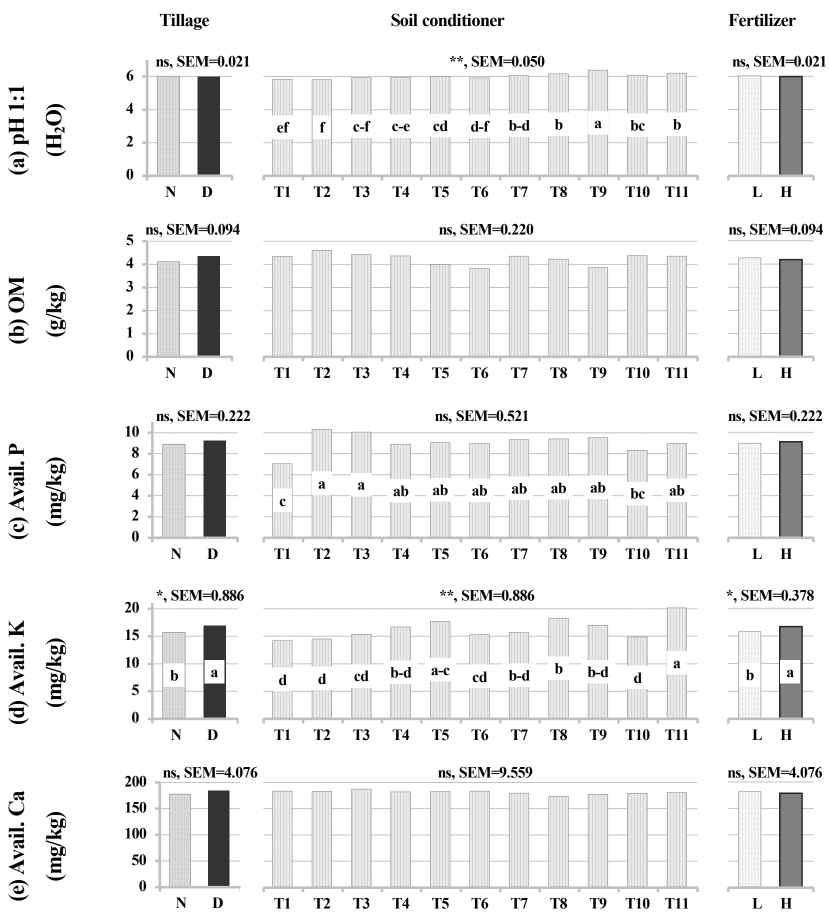


Figure 2 Effects of tillage, soil conditioners and chemical fertilizer on soil chemical property after growing cassava for one crop

It was evident that tillage, soil conditioner and chemical fertilizer had the effect on available potassium left in the topsoil. Deeper depth of the first plough (D) statistically resulted in greater amount of available potassium left in the soil than did shallower depth (N) of the first plough, giving the values of 16.82 compared to 15.45 mg/kg (Figure 2d). Applying ground limestone at the rate of 1,250 kg/ha (T11) highly significantly gave the highest available potassium of 20.01 mg/kg followed by 18.14 mg/kg which was obtained from the soil amended with dolomite at the rate of 625 kg/ha (T8). With no application of soil conditioner (T1), available potassium left in the soil was lowest. This might be due to all soil conditioners either have the ability to increase soil pH or contain cation exchange capacity to some extent, thus the application subsequently contributes the ability of the soil to retain potassium. In addition, raising soil pH can increase CEC and reduce leaching of K but, unless K is increased with lime, sorption and availability of K may be increased (von Uexkull, 1986). The application of 625 kg/ha (H) significantly promoted higher available potassium content than did the addition of 312.5 kg/ha (L), 16.73 compared to 15.55 mg/kg.

In addition, there was the interaction between tillage and chemical fertilizers of which deep tillage along with the addition of 625 kg/ha highly significantly gave the highest available potassium of 18.62 mg/kg left in the topsoil. Moreover, the interaction between soil conditioner and chemical fertilizers also had the influence on available potassium. Applying dolomite at the rate of 625 kg/ha with the addition of 625 kg/ha (T8H) highly significantly resulted in the highest available potassium of 22.30 mg/kg remained in the topsoil after harvesting cassava.

Deep tillage at the depth of 40-50 cm (D) and soil conditioner had no effect on available calcium left in the topsoil (Figure 2e) nor different type and rate of soil conditioners. Ritchey et al. (2004) reported that since only 34% of the Ca added as dolomite was extracted from the surface 15 cm, some of it may still have not dissolved, or it may have been solubilized by reactions with acid rain or N fertilizer and leached below 15 cm with sulfate or nitrate ions, lost by erosion, taken up by plants, moved downwards by soil fauna such as earthworms, or transformed into nonexchangeable forms. There were no different impacts of chemical fertilizer, the interactions between tillage and soil conditioner, tillage and chemical fertilizer, and soil conditioner and chemical fertilizer on the content of available calcium remained in the soil. The reason for subsoil amelioration is to improve rooting depth by increasing subsoil permeability. The lime should be incorporated in the soil as deeply as possible by a plough or disc harrow. It is because lime left on the soil surface may, depending on a soil's buffer capacity and amount of pH-dependent charge, react only with the surface layer (1-2 cm) of soil and not release Ca to move down the profile (Craswell, 1989). In the case of available magnesium, the application of bentonite at the rate of 1,250 kg/ha (T3) significantly gave the highest available magnesium of 29.03 mg/kg followed by 27.39 mg/kg obtained from the soil amended with perlite at the rate of 625 kg/ha (T4) (Figure 2f). This might be a coincidence as the control statistically gave no different amount and more noticeably the addition of dolomite significantly showed lower amount in spite of this material containing the highest amount of Mg when compared to the others.

Conclusions

Deep tillage to the depth of 45-50 cm clearly promoted greater fresh tuber and starch yields of cassava, Huay Bong 80 variety, than did normal tillage to the depth of 25-30 cm that was commonly operated by cassava growing farmers in the northeast. The additions of dolomite and ground limestone to condition this Typic Paleustult (Yasothon soil series) were more effective considering fresh tuber and starch yields obtained than did the applications of bentonite, perlite and gypsum. Growing cassava on this soil without using any soil conditioner gave the lowest yield. Furthermore, using of dolomite and ground limestone can improve soil pH and available P and K contents remained in the topsoil after growing cassava for one crop. In addition, nutrient concentrations positively correlated, to some degree, with cassava yield components, especially the concentrations of P in stem base, N, P, K, Ca and Mg in stem, Mn in leaf and branch with fresh tuber yield.

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