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Alleviation of Soil Compaction Problem for Growing Cassava on a Typic Paleustult, Northeast Thailand

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ABSTRACT

The combination effect of tillage and soil conditioner on the alleviation of soil compaction problem for growing cassava on a Typic Paleustult was conducted from May 2009 to March 2011. Deep tillage with soil conditioner applied had no effect on increased cassava yield in both years. Deep tillage practice together with the application of chicken manure gave the highest yield in the first year (19.88 t ha^{-1}) and with gypsum (23.13 t ha^{-1}) in the second year but with no statistical difference in both years. Both soil conditioners significantly induced the plant to have the lowest starch percentage of 21.7 and 24.6%, respectively. Ground limestone, gypsum and no amendments with and without deep tillage significantly gave the highest starch percentage in the first year while in the second year ground limestone, chicken manure and no amendment with conventional tillage had the same effect. Chicken manure highly significantly gave the highest above ground biomass by increasing stem, leaves and branches weight in the second year. There was no change of soil properties as the soil still containing very low amounts of organic matter and plant nutrient even though soil conditioner had been applied for two consecutive years. Chicken manure was the most efficient soil conditioner in increasing soil pH and enhancing plant nutrients availability while gypsum was the most effective source for alleviating soil compaction problem particularly more evidently at the depth between 20-30 cm. Nevertheless, soil compaction still remained after two-year application as shown by soil physical properties measured.

Key words: Deep tillage, gypsum, ground limestone, chicken manure, coarse textured soil

INTRODUCTION

Cassava (*Manihot esculenta* Crantz.) is an important economic crop of several countries including Thailand (OAE, 2010). In Thailand, cassava is grown on upland area, especially in the Northeast, where the coarse-textured soils are widespread. These soils have low agricultural potential because of its inherently low in plant nutrient and organic matter contents and cation exchange capacity resulting in low ability to retain plant nutrient which is the cause of nutrient losses in root zone (Duangpatra, 1988; Tongglum *et al*., 2000). Moreover, soil structure is weak so it is prone to erosion (Astier *et al*., 2006). Although, cassava is resistant to unfavorable conditions such as drought and acidic conditions and it can grow well in any soil types which are generally characterized by coarse texture with low fertility level (Duangpatra, 1988; Astier *et al.*, 2006; Tongglum *et al.*, 2000). However, on average yield in Northeast Thailand of current year only was 18.53 t ha^{-1} (OAE, 2010). One of major causes is soil compaction which is common in cassava growing areas in this region because cassava was been grown on the same area for a long time annually using heavy machine without proper soil improvement. Intensive tillage leads to rapid decomposition of organic matter, resulting in soil structure deterioration (Sittibusaya and Kurmarohita, 1987; Anusontpornperm *et al.*, 2005; Javadi and Spoor, 2006) and subsequent soil compaction that becomes a problem for plant growth (Martinez and Zinck, 2004; Meewassana, 2009; Kliaklom *et al.*, 2010). It has been shown that soil compaction limits both root and top growth of most agronomic crops, especially at the early stage of growth (Russell and Goss, 1974). Soil compaction also has negative effect on plant root growth through reducing the storage and water supply and nutrients. Adverse effect of soil compaction mainly occurs through decreasing macro porosity, increasing soil bulk density, increasing soil strength, decreasing soil water infiltration and water-holding capacity (Dexter, 2004), particularly in the subsoil compaction or so called plough pan. High bulk density decreases root length and increases average root diameter (Russell and Goss, 1974; Logsdon *et al.*, 1987). For tuberous crops such as cassava, this problem is severe due to it restricting the starch accumulation in tuber as a result of high soil strength and moisture deficit (Howeler, 1981). In addition, this compacted subsoil mainly impedes vertical drainage causing poor growth or tuber rot during the period of heavy rainfall that water logging on the top of plough pan or perched ground water is common (Schjonning and Rasmussen, 1994).

Tillage at different depth is well known to solve the compaction problem in soil by lowering bulk density (Celik *et al.*, 2004). Supplying nutrients and modifying soil physical properties improve crop growth and yield through changing the root environment which stimulates root growth and eventually increases biomass production (Darwish *et al.*, 1995) as shown in many reports. Riyaphan *et al.* (2010) found that using the ripper at 40 cm depth to break the plough pan in Typic Paleustult can increase cassava yield by 14.81% as compared to the others without rippering. CIAT (1988) reported that preparing the soil for growing cassava in Columbia by using 7-disc plough at approximately depth of 20 cm can increase cassava yield by 50% from the no till plot. This result agrees to other cases in China (Zheng *et al.*, 1992) and Philippines (Ohiri and Ezumah, 1990) as the yield upto 16.3 and 14.3%, respectively. In addition, the use of a subsoiler will help break the pan and improve internal drainage which tends to improve plant growth during the rain pelt and increase yields as a result (Wang *et al.*, 2008; Glab and Kulig, 2008).

Intensive tillage accelerates the break down of organic matter (Ohiri and Ezumah, 1990), in addition with the occurrence of plough pan in soil that becomes a problem (Anusontpornperm *et al.*, 2005; Kliaklom *et al.*, 2010; Meewassana, 2009). Although deep tillage can solve the compaction problem successfully, however, it is widely reported that subsoil become repeatedly compacted within 2-3 years after this operation (Hakansson *et al.*, 1996; Van Doren and Triplett, 1979). Therefore, a study on the effect of soil conditioners applied together with deep tillage on promoting better soil structure and increasing resistance to subsoil compaction should help increase yield of cassava.

MATERIALS AND METHODS

Study area and land preparation: Two years field experiment of tillage operation with different soil conditioners on growth of cassava was performed on Typic Paleustult, namely Yasothon soil series, in a farmer field at Dan Khun Tod district, Nakhon Ratchasima province (47 793630^{E},

Table 1: Initial properties of soils used in the experiment

Soil properties	Topsoil (0-18/20 cm)	Subsoil (18/20-60 cm)
pH (1:1 H_2O)	5.1	4.7
Organic matter (g kg^{-1})	4.2	3.30
Total N (g kg^{-1})	0.28	0.39
Available P (mg kg^{-1})	3.6	4.9
Available K (mg kg^{-1})	25.4	24.8
Extractable Ca ($cmol_c$ kg^{-1})	1.38	1.62
Extractable Mg ($cmol_c$ kg^{-1})	0.22	0.17
Extractable K ($cmol_c$ kg^{-1})	0.26	0.25
Extractable Na ($cmol_c$ kg^{-1})	0.46	0.38
Sum bases (cmol kg^{-1})	2.32	2.42
CEC ($cmol_c$ kg^{-1})	3.6	4.3

Table 2: Property of soil amendment used in the experiment

Properties	Gypsum	Ground limestone	Chicken manure
pH (1:5 H_2O)	7.5	8.9	7.00
EC (1:5 H_2O) (dS m^{-1})	2.76	0.07	1.50
OM (%)	na	na	40.60
CEC ($cmol_c$ kg^{-1})	na	na	65.08
Total N (%)	nd	nd	4.69
Total P (%)	0.22	0.37	0.76
Total K (%)	nd	0.03	1.76
Total Ca (%)	43.50	48.02	2.62
Total Mg (%)	0.06	5.36	0.32
Total Na (%)	0.01	0.25	1.14
Total S (%)	39.85	0.09	na
Total Fe (mg kg^{-1})	0.20	0.41	250.0
Total Zn (mg kg^{-1})	91	170	470.0
Total Cu (mg kg^{-1})	134	217	4.0
Total Mn (mg kg^{-1})	155	222	470.0

nd: Not detectable, na: Not determined

1676161^{N}). Plough pan was found in this soil at the depth between 15-25 cm (Meewassana, 2009). The site, approximately 1,260 m^2 in area, has an average slope of 3% towards the south east and is located on 245 m above MSL. The studied area is under a tropical savanna climate with rainfall being between 138 to 1,212 mm, most of it occurring between May and October. Properties of topsoil (0-18/20 cm) and subsoil (18/20-60 cm) prior to conducting the experiment were given in Table 1.

The treatments were arranged in a randomized complete block design and replicated four times. The treatment consisted of the control (T1) as no deep tillage before normal land preparation for growing cassava (using 3 disc plough to a depth of 15 cm followed by 7 disc plough and ridging) and with no soil conditioner application) and the others were deep tillage using 3-disc plough at 30 cm deep solely before normal land preparation (T2) and together with the applications of 1.25 t ha^{-1} of gypsum (T3), 1.25 t ha^{-1} of ground limestone (T4) and 6.25 t ha^{-1} of chicken manure (T5). Properties of soil conditioners used in this experiment were show in Table 2.

The area had been used for cassava cultivation for over 20 years before the establishment of the trial in 2009. The clearing operation was done manually followed by in situ burning after 2 weeks. Land preparation started from partition the area into size of 1008 and 252 m^2, respectively. The area with larger size was plough by using tractor equips with 3-disc plough at 30 cm deep and the other was left idle at the same time. After two week left, both sizes of the area was plough again by using tractor equips with 3-disc plough at 15 cm deep then separate area into the plot size of 6×8 m with the spacing between plots was 1 m after that the soil conditioners were applied to the plot according to the given treatment. One weeks after the incorporation of soil conditioners into the soil by using 7 disk plough at approximately of 15 cm deep then contour ridging was done for growing cassava, Huai Bong 80 cultivar, using cassava cuttings, 25 cm long, were planted in ridges at spacing of 80×120 cm. Cassava characters consisting of fresh roots and the yield of tops (leaf and branch, stem and stem basal) were recorded at 10 months after planting with the harvest area of 48 m^2. In the second year, there was no deep tillage implemented while soil conditions were applied similarly as in the first year. Conventionally tilled plots were ploughed at mid of April and planting of the entire field was done in mid of May for each year.

Cassava received 0.63 t ha^{-1} of complete fertilizer formula of 15-15-15, equally spit application at two and four months in both years. Pest and weed controls were performed according to general local practices and recommendations. All other necessary operations were kept normal and uniform for all treatments.

Soil sampling and analyses: Soil conditioner properties were analyzed. Soil samples from each plot were collected in mid March 2011, one week before the second crop being harvested with two spots of sampling for each plot. Disturbed and undisturbed soils were sampled at three following depths, 0-10, 20-30 and 40-50 cm.

Laboratory analyses of soil physio-chemical properties were undertaken based on standard methods. Undisturbed soil samples were collected by using soil core and dried at 105°C in an oven for determining bulk density (Blacke and Hartge, 1986) and saturated hydraulic conductivity by using variable head method (Klute, 1965). Other disturbed soil samples were air-dried, crushed and passed through a 2 mm sieve for general laboratory analyses. Soil pH was measured in water with a ratio of 1:1 and determined by pH meter (National Soil Survey Center, 1996). Total N content was determined by Kjeldahl method (Jackson, 1965). Organic carbon content was measured by the Walkley-Black titration method (Nelson and Sommers, 1996). Soil was extracted by Bray II method and subsequently available phosphorus content was determined by molybdate blue method (Bray and Kurtz, 1945). Available potassium was extracted from soil using 1 M NH_4OAc at pH 7.0 and the amount was measured by using Atomic Absorption Spectrophotometer (AAS) (Pratt, 1965).

Statistical analysis: All data were analyzed by using the analysis of variance (ANOVA) with SPSS program. The Duncan Multiple Range Test (DMRT) was used to compare the mean results and a significant variation is highlighted by ANOVA. The differences are considered significant if $p<0.05$.

RESULTS AND DISCUSSION

Characteristics of soil in the experimental area: The soil was classified as a Typic Paleustult, a sandy loam to sandy clay loam texture, it derived from residuum of sandstone parent material, having deep and well drained features. Sand, silt and clay contents were 647-736, 89-136 and 150-233 g kg^{-1}, respectively with clay content increasing with depth (Table 3). Soil structure was weak fine to medium subangular blocky in topsoils and weak to moderately medium to coarse sub-angular blocky in subsoil. Soil color ranged from red to dark red.

Table 3: Physical and chemical properties of Typic Paleustult

Depth (cm)	Hor.	Particle size distribution ($g\ kg^{-1}$) Sand	Silt	Clay	Textural class	Bulk density ($Mg\ m^{-3}$)	Ksat ($cm\ h^{-1}$)	pH (1:1 H_2O)	OM ($g\ kg^{-1}$)	Available ($mg\ kg^{-1}$) P	K	CEC ($cmol\ kg^{-1}$)	BS (%)
0-20	Ap1	736	113	150	SL	1.68	1.54	5.0	4.29	10.4	70.6	2.4	17.7
20-41	Bt1	678	131	191	SL	1.80	0.24	4.2	3.26	2.5	90.8	3.4	11.2
41-69	Bt2	662	137	199	SL	1.70	0.34	4.0	2.57	2.5	21.1	3.3	10.7
69-95	Bt3	651	115	233	SCL	1.57	1.54	4.0	2.75	2.5	17.8	3.4	8.6
95-120	Bt4	647	136	217	SCL	1.57	2.26	4.0	2.57	2.5	16.7	3.1	6.8
120-142	Bt5	680	124	196	SL	1.60	2.37	4.4	1.89	1.8	14.3	3.1	5.0
142-171	Bt6	699	89	212	SCL	1.61	1.54	4.3	1.54	1.4	15.5	3.0	6.9
171-200+	Bt7	658	112	229	SCL	1.61	1.19	4.2	0.86	1.4	17.9	2.6	9.7

SL: Sandy loam, SCL: Sandy loam clay

Table 4: Effect of soil amendments on yield and aboveground biomass of cassava grown on a compacted Typic Paleustult

Treatments	Tuber weight ($t\ ha^{-1}$) 2010	2011	Stem weight ($t\ ha^{-1}$) 2010	2011	Stem base weight ($t\ ha^{-1}$) 2010	2011	Leaves and branches weight ($t\ ha^{-1}$) 2010	2011	Aboveground biomass weight ($t\ ha^{-1}$) 2010	2011
CT+No soil amendment	19.2	18.3	4.9	1.7^c	2.6	2.9^b	1.0	4.9^c	2.8	9.4^c
DT+No soil amendment	13.3	14.3	6.6	1.6^c	3.4	3.0^b	2.4	4.4^c	4.2	9.0^c
DT+Gypsum	19.3	23.1	5.7	5.6^b	3.2	5.1^a	2.1	7.8^b	3.6	18.4^b
DT+Ground limestone	17.1	21.4	5.6	2.4^c	2.8	2.9^b	2.4	5.3^c	3.6	10.3^c
DT+Chicken manure	19.9	22.0	6.1	9.3^a	3.0	4.7^a	2.9	10.8^a	4.1	24.8^a
F-test	ns	ns	ns	**	ns	**	ns	**	ns	**

ns: Non significant, **Significant at 0.01 probability levels, mean with the different letters in column are significantly different to each other according to Duncan's Multiple Range Test (DMRT), CT: No deep tillage before conventional land preparation (3 disc followed by 7 disc plough and contour ridging), DT: Deep tillage by using 3 disc plough at depth of 30 cm before conventional land preparation

Bulk density value of soil was moderate to moderately high (1.57-1.80 $Mg\ m^{-3}$) correlated with slow to very slow saturated hydraulic conductivity value (0.24-2.37 $cm\ h^{-1}$). Bulk density generally increased from Ap-horizon to depth of 40 cm and then decreased with depth. The highest bulk density value was found at the depth of 30-40 cm (1.80 $Mg\ m^{-3}$) which was characterized by the Ksat value of less than 1 $cm\ h^{-1}$. This is indicator of the occurrence of plough pan in this soil. Therefore, this soil prone to compacted especially within 50 cm from the soil surface where the root zone. This compacted layer is one of the major problem that lower the yield of cassava grown on this soil type (Maduakor, 1993; Tongglum *et al.*, 2000). Apart from this compaction problem, the soil was very strongly to strongly acid (pH 4.0-5.0) and had very poor fertility status as reflected by low contents of organic matter (0.86-3.26 $g\ kg^{-1}$), available phosphorus (1.4-10.4 $mg\ kg^{-1}$), available potassium(14.3-90.8 $mg\ kg^{-1}$), base saturation percentage (5.0-11.2%) and cation exchange capacity (3.0-3.4 $cmol_c\ kg^{-1}$) (Table 3).

Cassava characters: The application of soil conditioner in two consecutive years statistically had no effect on cassava yield but resulted in differences of aboveground biomass in the second year and starch content in both years (Table 4 and 5). Deep tillage practice together with the application of soil conditioner increased yield of cassava by 28.8 and 35.4% when compared to only deep tillage

Table 5: Effect of soil amendments on surviv or rate and starch content of cassava grown on a compacted typic paleustult

	Survival rate (%)		Starch content (%)		Starch yield (t ha^{-1})	
Treatments	2010	2011	2010	2011	2010	2011
CT+No soil amendment	91.3^{ab}	87.5	26.0^{a}	28.9^{a}	5.1	5.3^{a}
DT+No soil amendment	88.3^{b}	86.0	26.6^{a}	21.1^{b}	4.8	3.0^{b}
DT+Gypsum	86.1^{b}	90.6	25.8^{a}	24.6^{b}	4.8	5.7^{a}
DT+Ground limestone	89.1^{b}	90.6	24.8^{a}	29.1^{a}	3.9	6.2^{a}
DT+Chicken manure	95.9^{a}	91.2	21.7^{b}	27.6^{a}	5.1	6.1^{a}
F-test	*	ns	*	*	ns	*

ns: Non significant, *Significant at 0.05 probability levels, mean with the different letters in column are significantly different to each other according to Duncan's Multiple Range Test (DMRT), CT: No deep tillage before conventional land preparation (3 disc followed by 7 disc plough and contour ridging), DT: Deep tillage by using 3 disc plough at depth of 30 cm before conventional land preparation

practice and 2.1 and 17.8% when compared to the control for the first and second years, respectively (Table 4). With no statistical difference, chicken manure applied together with deep tillage gave the highest tuber yield of 19.9 t ha^{-1} in the first year while in the second year gypsum application giving the highest tuber yield of 23.1 t ha^{-1} (Table 4). This is due to the compacted layers is destroyed by deep tillage practice. It subsequently improves internal drainage leading to an increasing of available water content in soil. This also tends to enhance root growth, especially when applies together with Ca-rich soil amendments (Brady and Weil, 2008; Glab and Kulig, 2008; Wang *et al.*, 2008) and subsequently results in an increase of cassava yield. Nevertheless, it possible that deep tillage can last only one season then the compacted layer can resurrect again as reflected by the lowest yield being observed in the control plot with no deep tillage and no soil condition application in both years (13.3 and 14.3 t ha^{-1} for the first and second year, respectively) (Table 4). This agrees with previous reports (Van Doren and Triplett, 1979; Ohiri and Ezumah, 1990; Glab and Kulig, 2008; Wang *et al.*, 2008; Riyaphan *et al.*, 2010) who found that subsoils could become compacted again within 2 or 3 years after breaking the pan.

Both soil conditioners (chicken manure and gypsum) was likely to increase cassava yield but significantly induced the plant to have the lowest starch percentage of 21.7 and 24.6%, for the first and second year, respectively (Table 5). Applications of ground limestone and gypsum and no amendment with and without deep tillage significantly gave the highest starch percentage in the range of 24.8-26.6% in the first year but, in the second year, additions of chicken manure and ground limestone and no amendment with conventional tillage (27.6-29.1%) significantly gave higher starch content than did the others. The application of chicken manure highly significantly induced the plant to produce the highest aboveground biomass, mainly by increasing stem and leaves and branches weights, in the second year. In addition, when compared among deep tillage treatments, the application of chicken manure statistically gave the highest survival percentage of 95.9% in the first year but with no statistical difference in the second year. This is because chicken manure contains higher contents of organic matter and nitrogen than do other soil conditioners used in this experiment (Table 2). After the decomposition of chicken manure, nitrogen released was the highest amount among soil conditioners (Brady and Weil, 2008); consequently, high nitrogen content could enhance plants in terms of vegetative growth rather than the increase of starch content in tuber as agreed with previous reports (Riyaphan *et al.*, 2010). As a result, cassava growth can respond better in the context of fresh tuber yield and aboveground biomass.

Table 6: Physical properties of a compacted typic paleustult as affected by different soil amendments

	Soil depth (cm)		
Treatments	0-10	20-30	40-50
Bulk deusity (Mg m^{-3})			
CT+No soil amendment	1.28	1.61	1.61
DT+No soil amendment	1.54	1.62	1.58
DT+Gypsum	1.41	1.56	1.60
DT+Ground limestone	1.49	1.57	1.56
DT+Chicken manure	1.45	1.67	1.63
F-test	ns	ns	ns
Hydraulic couductivity (cm h^{-1})			
CT+No soil amendment	1.53	0.08	0.07
DT+No soil amendment	3.45	0.50	0.09
DT+Gypsum	5.52	0.19	0.14
DT+Ground limestone	9.58	0.16	0.18
DT+Chicken manure	2.07	0.12	0.18
F-test	ns	ns	ns

ns: Non significant, CT: No deep tillage before conventional land preparation (3 disc followed by 7 disc plough and contour ridging), DT: Deep tillage by using 3 disc plongh at depth of 30 cm before conventional land preparation

Alleviation of the compaction problem: Although deep tillage practice together with soil conditioners were implemented in this compacted Typic Paleusult soil for two consecutive years, the compaction problem still remained in soils within 50 cm depth as reflected by unchanged physical soil properties (Table 6). For instance, bulk density values were still high and hydraulic conductivity values remained low. Soil in the plot with no deep tillage practice and soil conditioner applied had the highest bulk density which coincided with the slowest hydraulic conductivity especially at the depth between 20-50 cm but with no statistical difference. Deep tillage together with the addition of gypsum had a trend of decreasing bulk density more than other soil conditioners, particularly at the depth between 20-30 cm which coincided with better yield retrieved, although the statistical analysis did not show any difference. Whereas, the application of ground limestone increased the hydraulic conductivity of topsoil with the values of 9.58 cm h^{-1}, faster than other soil conditioners. These results are the same as quoted by numerous reports (Hamza and Anderson, 2003; Horn and Smucker, 2005; Lipiec *et al.*, 2007) because these two soil conditioners can effectively loosen soil structure and subsequently enhance water movement in the soil due to Ca and Mg contained in these materials (Favaretto *et al.*, 2006; Brady and Weil, 2008).

Organic matter and plant nutrient content: There was no clear effect of deep tillage and soil conditioners on organic matter, total nitrogen, available phosphorus and available potassium contents with the amount ranging from 0.30-0.47 g kg^{-1}, 0.26-0.36 g kg^{-1}, 4.68-57.58 mg kg^{-1} and 29.62-77.66 mg kg^{-1}, respectively at the time of harvest in the second year (Table 7). Soil in the experimental area still contained low amounts of organic matter and plant nutrients. However, these contents were still higher in the plots applied with soil conditioner when compared with the control and only deep tillage treatment. This reflects the nature of these coarse-textured soils, having very low organic matter and cation exchange capacity, that was incapable of retaining plant nutrients within the soils against leaching (Astier *et al.*, 2006; Brady and Weil, 2008) and soil conditioners having been applied for two consecutive year still had little effect in this respect.

Table 7: Chemical properties of a compacted Yasothon soil as affected by different soil amendments

	Soil depth (cm)		
Treatments	0-10	20-30	40-50
Soil pH (1:1H_2O)			
CT+No soil amendment	4.85	5.12	4.98^{a}
DT+No soil amendment	5.00	5.05	4.68^{b}
DT+Gypsum	5.15	5.00	4.78^{ab}
DT+Ground limestone	4.98	5.18	4.73^{ab}
DT+Chicken manure	5.65	5.30	4.83^{ab}
F-test	ns	ns	*
Organic matter (g kg^{-1})			
CT+No soil amendment	0.47	0.42	0.33
DT+No soil amendment	0.42	0.41	0.36
DT+Gypsum	0.40	0.37	0.36
DT+Ground limestone	0.46	0.47	0.30
DT+Chicken manure	0.46	0.44	0.39
F-test	ns	ns	ns
Total N (g kg^{-1})			
CT+No soil amendment	0.32	0.30^{ab}	0.26
DT+No soil amendment	0.30	0.33^{ab}	0.31
DT+Gypsum	0.30	0.29^{b}	0.30
DT+Ground limestone	0.33	0.31^{ab}	0.31
DT+Chicken manure	0.36	0.36^{a}	0.35
F-test	ns	*	ns
Available P (mg kg^{-1})			
CT+No soil amendment	19.98	7.50	4.96^{a}
DT+No soil amendment	19.04	9.01	4.68^{b}
DT+Gypsum	26.35	6.14	4.78^{ab}
DT+Ground limestone	15.03	10.63	4.73^{ab}
DT+Chicken manure	57.58	19.77	4.83^{ab}
F-test	ns	ns	*
Available K (mg kg^{-1})			
CT+No soil amendment	48.70	31.81	29.62
DT+No soil amendment	56.19	35.52	31.78
DT+Gypsum	55.17	40.68	32.12
DT+Ground limestone	46.22	33.67	29.20
DT+Chicken manure	77.66	47.48	60.14
F-test	ns	ns	ns

ns: Non significant, *Significant at 0.05 probability levels, mean with the different letters in column are significantly different to each other according to Duncan's Multiple Range Test (DMRT), CT: No deep tillage before conventional land preparation (3 disc followed by 7 disc plough and contour ridging), DT: Deep tillage by using 3 disc plough at depth of 30 cm before conventional land preparation

The application of chicken manure was, however, likely to efficiently increase soil pH and the availability of plant nutrients, especially in the case of phosphorus and potassium. The effect was higher than the applications of gypsum and ground limestone even though there was no statistical difference. This is due to a high cation exchange capacity of chicken manure leading to more amounts of plant nutrients stored in soils (Brady and Weil, 2008).

Moreover, chicken manure contained much more varieties of plant nutrient than did other two soil conditioners, therefore, decomposition of chicken manure released more plant nutrients to the soils. Also, chicken manure slightly increases soil pH, then resulting in increasing phosphorus availability (Brady and Weil, 2008) whereas, gypsum and ground limestone contain high amount of Ca that is likely to replace K leading to the loss of K by leaching (Mengel and Kirkby, 1987).

CONCLUSION

Deep tillage to the depth of 30 cm did not improve yield of cassava grown on a compacted Typic Paleustut, except when applied together with soil conditioners. Deep tillage together with the application of gypsum at the rate of 1.25 t ha^{-1} was found the most suitable for cassava grown on this soil, potentially giving the maximum yield but with the lowest starch content in tuber. Moreover, this combined practice had a trend of better alleviating the problem of soil compaction than did other soil conditioners. However, the compaction still remained a problem for growing cassava in this soil although soil conditioners had been applied for two consecutive years. In terms of plant nutrient stored in soil after two crops of cassava, chicken manure at the rate of 6.25 t ha^{-1} is likely to be the best practice for preservation of organic matter and plant nutrient in the soil. Based on this result, the application of gypsum together with chicken manure might be able to both alleviate soil compaction problem and increase cassava yield but further research needs be conducted.

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