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Characteristics and fertility capability of cassava growing soils under different annual rainfall conditions in Northeast Thailand

Sattha Boonrawd[1], Somchai Anusontpornperm[1]*, Suphicha Thanachit[1], Irb Kheoruenromne[1] and Naruekamol Janjirawuttikul[2]

[1] *Department of Soil Science, Faculty of Agriculture, Kasetsart University, Bangkok, 10900*
[2] *Soil Resources Survey and Research Division, Land Development Department, Bangkok, 10900*

ABSTRACT: Eight soils from major cassava fields in Ubon Ratchathani (higher rainfall: KL13, KD3, NK9 and NP27 pedons) and Nakhon Ratchasima (lower rainfall: SP3, SP4, SP5 and SP6 pedons) provinces were selected, objectively to investigate their characteristics and evaluate their fertility potential for making a guidance of soil and fertilizer management for cassava crop cultivation. Soil samples were collected from genetic horizon of each soil for the analyses of soil physico-chemical properties basing on standard methods. Result revealed that the soils were deep soils, derived from alluvial deposit and residuum of sandstone-related rocks. They had loamy sand and sandy loam textures as sand particle dominated throughout their profile and clay increased with depth. All soils were classified as Typic Paleustults. Plough pan was observed in KD3, SP3, SP4 and SP5 pedons of which the layer underneath A horizon had markedly greater bulk density than did overlying and underlying horizons. They were acidic and had low fertility level in both topsoil and subsoil except topsoil of KD3 soil that had medium level. According to Fertility Capability Classification (FCC), these soils similarly shared 'd' and 'e' modifiers, indicating that they had dry period of >60 consecutive day/yr and intense leaching. The KD3, NK9, NP27 and SP3 soils contained 'a' modifier which illustrated a potential of aluminium toxicity problem while KD3, NK9, SP4, SP5 and SP6 pedons were subject to K deficiency as shown by their 'k' modifier. With regard to characteristics and fertility capability of these soils, managing these soils for cassava cultivation must place emphasis on careful nutrient management, especially K, as leaching is the key problem in addition with organic matter augmentation to minimize damage of doughtiness with no exception of the soils in Ubon Ratchathani.
Keywords: soil property; FCC; soil fertility; cassava

Introduction

Significant land use changes in northeast Thailand associated with the clearing of climax Dipterocarp forests for the production of agricultural commodities, has resulted in major declines in soil chemical, physical and biological attributes (Imsamut and Boonsompoppan, 1996; Kheoruenromne et al., 1998; Bruand et al., 2004; Anusontpornperm et al., 2009). Cassava and sugarcane are dominant in this region where lowland area is used for paddy rice. Most of cassava growing soils are classified into Ultisols such as a Korat, Warin, Yasothon and Satuk soil series (Anusontpornperm et al., 2009; Anusontpornperm et al., 2018). These soils are mostly course textured soils, having particle size class in the range of sandy loam, sandy clay loam and loamy sand. The soils have low fertility, low organic matter (OM) content, low cation exchange capacity (CEC), very low buffering capacity and low surface

* Corresponding author: somchai.a@ku.ac.th
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charge characteristics (Ogawa et al., 1980; Yuvanuyama, 2001; Anusontpornperm et al., 2009; Anusontpornperm et al., 2018). They also have low water holding capacity with rapid infiltration rate, making them very susceptible to moisture deficiency (Kheoruenromne et al., 1998). In such conditions, most fertilizers applied were leached from the soil or flushed away from the rhizosphere of the crops (Nakaviroj, 1998). Drainage is moderate to excessive but can also be poor if there is a subsurface compaction, fragipan and hardpan (Panichapong, 1988) as recently reported in cassava and sugarcane growing areas in Nakhon Ratchasima and Khon Kaen and other provinces (Anusontporperm et al., 2005; Kliaklom et al., 2010; Meewassana et al., 2010; Anusontpornperm et al., 2015). In this region, most cassava is grown as a sole crop (Howeler, 1988) on undulating and rolling topography where considerable soil loss due to severe erosion is common. With no soil erosion control measure coupled with continuous cassava cultivation without an appropriated fertilizer application (Sittibusaya et al., 1987; Howeler, 1991) and nutrient removal with cassava tuberous roots, these soils have severely been degraded, leading to a reduction of soil productivity. Soil and fertilizer management must have been adjusted; thus, this study was undertaken to investigate current characteristics and potential of soils in cassava growing areas in the northeast Thailand that were under different annual rainfalls objectively to provide guidance for soil and fertilizer management practices of which the outcomes would be beneficial to soil information users and agricultural extensionists involving cassava production in the region.

Materials and Method

Four soils were chosen from cassava fields in Ubon Ratchathani province where average annual rainfall was higher (1981-2010 = 1,581.7 mm) and the other 4 soils were selected from cassava fields in Nakhon Ratchasima province where average annual rainfall was lower (1981-2010 = 1,063.3 mm). Based on Soil Taxonomy classification system, all soils were classified as Typic Paleustults. Field study included general information of sites chosen and soil morphological identification using pedon analysis based on standard methods (Soil Survey Division Staff, 1993). Laboratory analyses comprised physical and chemical properties of soil samples collected from genetic horizons of each soil pedon using standard methods for soil analysis. Evaluation of soil fertility status (Soil Survey and Classification Division, 2000; Land Classification Division and FAO Project Staff, 1973) and Fertility Capability Classification (FCC) (Yost et al., 1997; Sanchez et al., 2003) were performed using morphological information and analytical data obtained from field study and laboratory analysis. In the case of FCC, modifiers used in the system comprised, for instance, d: strong dry season (ustic or xeric soil moisture regime: dry >60 consecutive days/year but moist >180 cumulative days/year within 20– 60 cm depth), e: high leaching potential (< 4 $cmol_c$/kg soil as ECEC, or < 7 $cmol_c$/kg soil by sum of cations at pH 7, or < 10 $cmol_c$/kg soil by sum of cations $+Al_3{}^{+}+H^{+}$ at pH 8.2), a: aluminum toxicity for most common crops (>60% Al saturation within 50 cm, or < 33% base saturation of CEC (BS7) determined by sum of cations at pH 7 within 50 cm, or < 14% base saturation of CEC (BS8.2) by sum of cations at pH 8.2 within 50 cm, or pH < 5.5 except in organic soils), and k: low nutrient capital reserves (< 10% weatherable minerals in silt and sand fraction within 50 cm, or siliceous mineralogy, or exchangeable K < 0.20 $cmol_c$/kg soil, or exchangeable K < 2% of sum of bases, if sum of bases is < 10 $cmol_c$/kg soil) (Sanchez et al., 2003).

Results and discussion

General information of soils chosen

There were 8 soils, namely SP3, S4, SP5 and S6 located in Nakhon Ratchasima province and KL13, KD3, NK9 and NP27situated in Ubon Ratchathan, northeast Thailand. General characteristics of these selected soils are shown in **Table 1**. The soils were very deep soil, having surface thickness in the range of 15/17-30 cm. Their profile development was genetically similar (Ap-Bt) and characterized by a presence of argillic horizon. Water-logged horizon (Btg) was found in the lower part of KL13 and NK9 pedons. The soils in Ubon Ratchathani were developed on the upper part of low terrace (NK9) to various positions of middle terrace (KL13, KD3 and NP27 pedons) while those in Nakhon Ratchasima being found on lower middle slope up to crestal slope of low hill. Most soils had well drained nature with the exception of KL13 and NK9 pedons that had moderately well drained feature. Almost all soils in Ubon Ratchathani were derived from alluvial materials except NP27 pedon that was derived from a residuum of sandstone whereas all soils in Nakhon Ratchasima were formed from the residuum of conglomeratic sandstone throughout their profile or underlying wash or local alluvial materials.

Physical property of selected soils

Physical property of soils chosen is presented in **Table 2**. Sand particle was dominant in all soils. Silt content was higher in soils from Ubon Ratchathani than in those from Nakhon Ratchasima. Clay content increased with increasing depth in all soils, but the proportion was very small compared to sand particle. Textural class of these soils was only loamy sand and sandy loam.

Bulk density of each horizon varied rather greatly within soil profile and among soils studied. However, the value tended to increase with increasing depth in all soils due mainly to the accumulation of clay content in subsoils. Plough pan was found in KD3, SP3, SP4 and SP5 soils indicated by greater bulk density of this dense layer than overlying and underlying layers. Hydraulic conductivity of these soils tended to decrease with depth and the value in plough pan layer was rather lower than in other horizons.

Chemical property of selected soils

Results of chemical property are subdivided into soil pH and nutrient status (**Figure 1**) and exchange property of the soils (**Figure 2**). Soil pH values were in the ranges of 4.4-6.5 and 3.0-6.1 when measured in H_2O and KCl, respectively, with the trend of decreasing values with depth. Organic matter content and total nitrogen contents of the soils were very low with topsoil layer containing the highest amount and the contents markedly decreasing with depth within soil profile. Available P content was generally very low in both topsoil and subsoil, except KL13, NK9 and NP27 pedons that had slightly higher in the topsoil. Available K was considerably very low throughout all soil profiles with only the topsoil of KD3 soil that was extraordinarily high (99.19 mg/kg). The soils in Ubon Ratchathani province were dominated by Ca followed by K whilst Mg and Na being very little. In contrast, these bases in the soils from Nakhon Ratchasima province were lower, but dominated by K other than Ca. Overall, soils from both areas had very low content of extractable bases (< 2 $cmol_c$/kg). Extractable acidity was very low to moderate and tended to increase slightly in the lower part of most soil profiles. Cation exchange capacity (CEC) by

NH_4OAc at pH 7 was mostly lower than 10 $cmol_c$/kg. Base saturation percentage of these soils was low to moderate with lower values in the lower part of soils.

Fertility status of soils chosen

Fertility level assessment of these soils revealed that they were low fertile in both topsoil and subsoil except KD3's topsoil that had medium fertility level because of very high available K content in the layer. Almost all properties used in this assessment were almost identically low despite these soils being under different amounts of annual rainfall. It was noticeable that all soils have very low score of OM and CEC whereas available P and K were scored medium only in very few numbers of soils.

Fertility capability classification (FCC) unit of soils chosen

Based on some selected physical and chemical properties, FCC units of soils selected in this study can be assessed based on FCC version 4 (Sanchez et al., 2003) and are presented in **Table 4**. At the Type level, sandy and loamy topsoil types were predominant in these soils studied with only SP3 and SP4 pedons containing substrata type of loamy subsoil. All soils had 'd' modifier as they were under ustic soil moisture regime. The KD3, NK9, NP27 and SP3 pedons had 'a' modifier owing to their soil pH of lower than 5.5, indicating a potential of aluminium toxicity for most common crops. The KD3, NK9, SP4, SP5 and SP6 pedons were composed of 'k' modifier, demonstrating low nutrient capital reserves, K deficiencies, of these soils. All soils shared the same 'e' modifier, signifying high leaching potential due to low buffering capacity of these soils.

The soils selected in this study have rather similar characteristics, morphologically, physically, and chemically, despite having formed under different rainfall conditions. They have good aeration topsoil as their texture is quite coarse to coarse which favours tuberization of cassava (Howeler, 2002) but with low plant nutrients and ability to retain nutrients and soil moisture as shown by several reports (Ogawa et al., 1980; Yuvanuyama, 2001; Anusontpornperm et al., 2009; Anusontpornperm et al., 2018). Plough pan in KD3, SP3, SP4 and SP5 soils as a result of improper tillage is similar to those investigated in cassava and sugarcane fields in the northeast (Anusontpornperm et al., 2005; Kliaklom et al., 2010; Meewasana et al., 2010). This impeded layer can adversely cause root elongation (Bennie, 1991), reduce the ability of plant to take up moisture stored underneath this layer, impede water and air movement to plant roots (Coelho et al., 2000), and initiate perched ground water on the top of this layer (Mc Danial et al., 2008). The latter can indeed be a major problem that leads to cassava tuber rot. Using ripper to break down is not so effective as its effect lasts only 1 year (Surin et al., 2013; Anusontpornperm et al., 2015) while deep tillage using 28-inch diameter disc having been proved more efficient (Lunlio et al., 2017). In addition, KL13 and NK9 pedons can experience a tuber rot due to them having Btg layer at 50 and 68 cm, respectively, of which during rainy season groundwater fluctuation can reach rooting zone of cassava for some time. The problem arises as cassava cannot be tolerant to waterlogging. Cassava tuber rot as affected by waterlogging reportedly caused a yield reduction of 72% in Africa and 47% Americas (Henry and Gottret, 1996.). As a result, growing cassava in these two soils should be commenced at nearly the end of rainy season to avoid this problem.

Fertility status of these soils, no matter how much the rainfall is, is poor, illustrating the inability of cassava growers in both areas to improve quality of the soils. Soil erosion control and OM management need to be prioritized first.

The application would have to be repeated as shown by the use chicken manure (Nilnoree et al., 2016), burnt rice husk from ethanol plant (Kerdchana et al., 2014) and wastes from cassava starch manufacturing plant (Phun-iam et al., 2018) as soil amendment. Regarding plant nutrient data obtained in this study and NPK fertilizer recommendation for cassava planted in light-textured upland Ultisols (Sittibusaya, 1996), 100:50:100 kg/ha of $N:P_2O_5:K_2O$ should be recommended for cassava planted in SP3, SP4, SP5, SP6 and NK9 soils as they have OM, available P and K of <6.5 g/kg, 5 and 30 mg/kg, respectively, 100:25:100 kg/ha of $N:P_2O_5:K_2O$ for KL13 and NP27 pedons due to them having available P of >5 mg/kg, 50:50:50 kg/ha of $N:P_2O_5:K_2O$ for KD soil which is consistent with its medium fertility status in topsoil.

Table 1 General characteristics of soils chosen

Thickness of surface horizon(cm)	Effective depth (cm)	Profile development	Slope (%)	Relief	Physiographic position/drainage	Parent materials /natural vegetation or land use
KL13: Ban Khee Lek, Na Dee subdistrict, Na Yia district, Ubon Ratchathani province						
28	200+	Ap-Bt-Btg1-Btg2-Btg3-Btg4-Btg5-Btg6	2	Slightly undulating	Lower part of middle terrace/ moderately well drained	Local Alluvium/ cassava field
KD3: Ban Khaeng Dom, Khaeng Dom subdistrict, Sawang Werawong district, Ubon Ratchathani province						
30	200+	Ap-Bt1-Bt2-Bt3-Bt4-Bt5-Bt6-Bt7	1	Nearly flat	Middle terrace/ well drained	Old alluvium/ cassava field
NK9: Ban Kum Klang, Khaeng Dom subdistrict, Sawang Werawong district, Ubon Ratchathani province						
31	200+	Ap1-Ap2-E-Btg1-Btg2-Btg3-Btg4-Btg5	2	Slightly undulating	Upper part of low terrace/ moderately well drained	Wash over old alluvium/ cassava field
NP27: Ban Nong Pan, Na Dee subdistrict, Na Yia district, Ubon Ratchathani province						
30	200+	Ap-Bt1-Bt2-Bt3-Bt4-Bt5-Bt6-Bt7	4	Undulating	Middle terrace/ well drained	Residuum derived from sandstone/ cassava field
SP3: Ban Supplu Noi, Huay Bong subdistrict, Dan Khun Thot district, Nakhon Ratchasima province						
18/21	200+	Ap-Bt-Bt2-Bt3-Bt4-Bt5-Bt6-Btc	4	Undulating	Crestal slope of low hill/ well drained	Residuum derived from conglomeratic sandstone/ cassava field
SP4: Ban Supplu Noi, Huay Bong subdistrict, Dan Khun Thot district, Nakhon Ratchasima province						
15/17	200+	Ap-Bt1-Bt2-Bt3-Bt4-Bt5-Bt6-Bt7-Bt8	5	Undulating	Middle slope of low hill/ well drained	Local alluvium over residuum derived from sedimentary rock mainly conglomeratic sandstone/ cassava field
SP5: Ban Supplu Noi, Huay Bong subdistrict, Dan Khun Thot district, Nakhon Ratchasima province						
25/30	200+	Ap1-Bt1-Bt2-Bt3-Bt4-Bt5-Bt6-Bt7	5	Undulating	Lower middle slope of low hill/ well drained	Wash over residuum derived from conglomeratic sandstone/ cassava field
SP6: Ban Supplu Noi, Huay Bong subdistrict, Dan Khun Thot district, Nakhon Ratchasima province						
20	200+	Ap-Ap2-Bt1-Bt2-Bt3-Bt4-Bt5-Bt6-Bt7	6	Undulating	Lower middle slope of low hill/ well drained	Wash over residuum derived from conglomeratic sandstone/ cassava field

Table 2 Some physical properties of soils chosen

Profile code	Horizon	Depth	Particle size distribution			Textural class	Bulk density	Hydraulic conductivity
			Sand	Silt	Clay			
		(cm)	(g/kg)				(Mg/m)	(cm/hr)
KL13	Ap	0-28	686	263	51	Sandy loam	1.32	2.24
	Bt	28-51	677	236	87	Sandy loam	1.57	0.79
	Btg1	51-76	677	243	80	Sandy loam	1.57	2.33
	Btg2	76-100	679	253	68	Sandy loam	1.58	0.35
	Btg3	100-130	722	213	65	Sandy loam	1.53	0.19
	Btg4	130-157	685	236	79	Sandy loam	1.47	0.59
	Btg5	157-180	642	274	84	Sandy loam	1.66	0.02
	Btg6	180-200+	606	272	122	Sandy loam	1.67	0.14
KD3	Ap	0-30	736	194	70	Sandy loam	1.52	1.08
	Bt1	30-56	710	200	91	Sandy loam	1.85	2.74
	Bt2	56-72	732	188	80	Sandy loam	1.52	0.69
	Bt3	72-110	742	184	74	Sandy loam	1.59	0.50
	Bt4	110-136	742	177	81	Sandy loam	1.53	0.44
	Bt5	136-160	733	191	76	Sandy loam	1.57	0.79
	Bt6	160-185	726	191	83	Sandy loam	1.65	0.64
	Bt7	185-200+	649	222	129	Sandy loam	1.59	0.83
NK9	Ap1	0-31	780	205	15	Loamy sand	1.23	7.05
	Ap2	31-48	767	215	18	Loamy sand	1.47	2.08
	E	48-68	806	185	9	Loamy sand	1.47	3.03
	Btg1	68-107	804	182	14	Loamy sand	1.44	1.14
	Btg2	107-125	820	160	20	Loamy sand	1.63	2.55
	Btg3	125-153	768	220	12	Loamy sand	1.71	0.10
	Btg4	153-180	655	246	99	Sandy loam	1.73	0.07
	Btg5	180-200+	651	255	94	Sandy loam	1.73	2.80
NP27	Ap	0-30	836	132	32	Loamy sand	1.35	4.91
	Bt1	30-53	813	122	65	Loamy sand	1.44	1.02
	Bt2	53-80	819	121	60	Loamy sand	1.51	1.55
	Bt3	80-102	806	120	74	Loamy sand	1.92	2.73
	Bt4	102-131	789	126	85	Loamy sand	1.72	4.22
	Bt5	131-150	780	126	94	Sandy loam	1.70	1.36
	Bt6	150-180	784	122	94	Sandy loam	1.63	0.15
	Bt7	180-200+	772	133	95	Sandy loam	1.64	0.43
SP3	Ap	0-18/21	831	89	80	Loamy sand	1.55	2.52
	Bt1	21-43	781	97	122	Sandy loam	1.79	0.53
	Bt2	43-68	769	84	148	Sandy loam	1.60	4.26
	Bt3	68-90	747	97	156	Sandy loam	1.64	3.49
	Bt4	90-118	721	81	198	Sandy loam	1.60	3.59
	Bt5	118-150	704	102	194	Sandy loam	1.63	2.84
	Bt6	150-175	736	87	177	Sandy loam	1.64	6.20
	Btc	175-200+	718	109	173	Sandy loam	1.68	0.05

Table 2 (Cont.)

Profile code	Horizon	Depth	Particle size distribution			Textural class	Bulk density	Hydraulic conductivity
			Sand	Silt	Clay			
		(cm)	(g/kg)				(Mg/m)	(cm/hr)
SP4	Ap	0-15/17	828	100	72	Loamy sand	1.52	5.71
	Bt1	15-30	791	125	84	Sandy loam	1.62	3.84
	Bt2	30-65	780	119	101	Sandy loam	1.56	5.40
	Bt3	65-90	801	119	80	Loamy sand	1.45	2.90
	Bt4	90-117	790	117	93	Sandy loam	1.55	3.99
	Bt5	117-142	781	114	105	Sandy loam	1.51	2.22
	Bt6	142-168	786	87	127	Sandy loam	1.45	4.57
	Bt7	168-190	767	110	123	Sandy loam	1.53	2.21
	Bt8	190-210+	789	81	130	Sandy loam	1.50	1.04
SP4	Ap	0-15/17	828	100	72	Loamy sand	1.52	5.71
	Bt1	15-30	791	125	84	Sandy loam	1.62	3.84
	Bt2	30-65	780	119	101	Sandy loam	1.56	5.40
	Bt3	65-90	801	119	80	Loamy sand	1.45	2.90
	Bt4	90-117	790	117	93	Sandy loam	1.55	3.99
	Bt5	117-142	781	114	105	Sandy loam	1.51	2.22
	Bt6	142-168	786	87	127	Sandy loam	1.45	4.57
	Bt7	168-190	767	110	123	Sandy loam	1.53	2.21
	Bt8	190-210+	789	81	130	Sandy loam	1.50	1.04
SP5	Ap	0-25-30	782	125	93	Sandy loam	1.53	3.93
	Bt1	30-50/56	816	79	105	Sandy loam	1.71	2.79
	Bt2	56-79	774	96	130	Sandy loam	1.52	1.33
	Bt3	79-102	762	95	143	Sandy loam	1.59	4.97
	Bt4	102-130	775	77	148	Sandy loam	1.62	5.08
	Bt5	130-156	751	89	160	Sandy loam	1.64	3.56
	Bt6	156-179	771	86	143	Sandy loam	1.70	1.56
	Bt7	179-200+	857	63	80	Loamy sand	1.66	3.72
SP6	Ap1	0-20	817	107	76	Loamy sand	1.50	5.91
	Ap2	20-40	860	73	67	Loamy sand	1.43	3.64
	Bt1	40-63	843	89	68	Loamy sand	1.59	1.42
	Bt2	63-88	836	97	67	Loamy sand	1.60	0.39
	Bt3	88-112	832	113	55	Loamy sand	1.63	3.42
	Bt4	112-135	828	104	68	Loamy sand	1.68	1.45
	Bt5	135-163	836	80	84	Loamy sand	1.75	0.29
	Bt6	163-185	822	89	89	Loamy sand	1.72	0.24
	Bt7	185-200+	779	73	148	Sandy loam	1.74	0.34

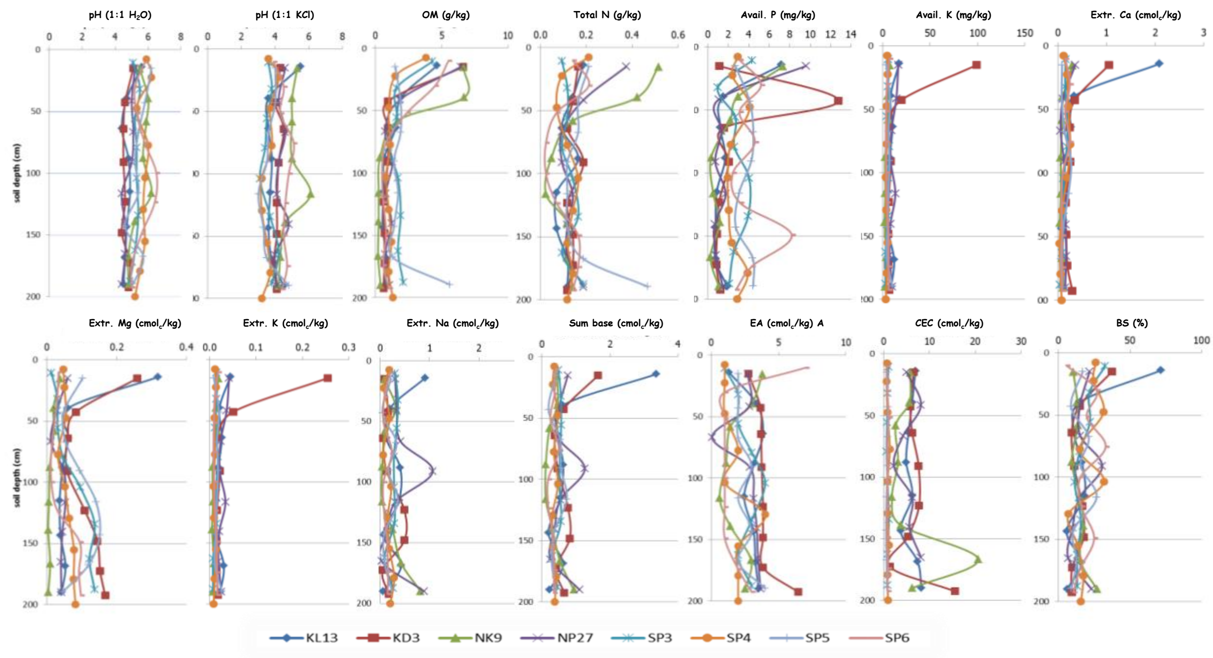

Figure 1 Soil pH, nutrient status and exchange property of soils chosen

FCC unit of these soils as mentioned earlier, shared some modifiers in common. Despite the soils from Ubon Ratchathani province being under much higher rainfall, rainfall distribution during dry months is the same as that of Nakhon Ratchasima province (Thai Meteorological Department, 2020); thus, 'd' modifier is fit to these sets of soils. The difference is the amount of rainfall during rainy season which cassava planted in the former province in the early rainy season would receive more rain during early growth stage which can be harmful in terms of weeds pandemic and waterlogged condition, particularly those in KL13 and NK9. In the opposite direction, the plant grown in KD3 and NP27 would be benefited from high intensity of rain during this stage of growth. The other shared-modifier is 'e', which comes with no surprise as all soils chosen are inherently low fertile with rather coarse to coarse texture nature due to their parent material, resulting in these soils having low CEC (Figure 2). This demonstrates low efficiency of chemical fertilizer usage, particularly N and K in these soils. Soil organic materials such as cassava tails and stalk (Jenwitheesuk et al., 2018), cassava starch waste (Phun-iam et al., 2018), burnt rice husk (Ruenchan et al., 2018) and chicken manure (Nilnoree et al., 2016) proved to enhance the efficiency of chemical fertilizer well. This is particularly in KD3, NK9, SP4, SP5 and SP6 soils that are composed of 'k' modifier which shows a lack of K reserve. Therefore, the increase of OM and subsequent CEC is essential in these soils. Lastly, 'a' modifier that appears in KD3, NK9, NP27 and SP3 soils which suggests a potential of Al toxicity. As far as the tolerance of cassava to high soil acidity is concerned, Howeler (1991) reported that cassava could tolerate high levels of Al in the soil solution, hence, this modifier might not be a case for this plant whatsoever. Other attributes as mentioned by Sanchez et al. (2003) that can improve FCC for particular crops, especially cassava, should be emphasized to make this fertility classification more interpretative (Anusontpornperm et al., 2009).

Table 3 Fertility status of soils chosen

Profile code	Depth (cm)	OM[a] (g/kg)		BS[e] (%)		CEC[d] ($cmol_c$/kg)		Avail. P[b]		Avail. K[c]		Total Score	Fertility rating
								(------------mg/kg------------)					
KL13	Topsoil	4.6	(1)	71.69	(2)	6.9	(1)	7.18	(1)	17.27	(1)	6	low
	Subsoil	2.0	(1)	15.21	(1)	6.2	(1)	1.52	(1)	8.20	(1)	5	low
KL27	Topsoil	5.0	(1)	26.75	(1)	2.9	(1)	15.09	(2)	16.07	(1)	6	low
	Subsoil	4.2	(1)	24.86	(1)	4.3	(1)	10.73	(2)	11.85	(1)	6	low
KD3	Topsoil	6.2	(1)	37.34	(2)	6.5	(1)	1.12	(1)	99.19	(3)	8	medium
	Subsoil	0.9	(1)	14.78	(1)	5.8	(1)	12.74	(2)	19.81	(1)	6	low
NK9	Topsoil	6.6	(1)	10.42	(1)	5.8	(1)	7.32	(1)	7.14	(1)	5	low
	Subsoil	6.7	(1)	13.15	(1)	5.6	(1)	2.93	(1)	5.11	(1)	5	low
NP27	Topsoil	6.4	(1)	21.73	(1)	5.0	(1)	9.56	(1)	16.31	(1)	5	low
	Subsoil	1.8	(1)	15.14	(1)	8.1	(1)	1.05	(1)	14.25	(1)	5	low
SP3	Topsoil	4.3	(1)	32.61	(1)	1.0	(1)	4.32	(1)	5.67	(1)	5	low
	Subsoil	1.6	(1)	21.62	(1)	0.8	(1)	0.97	(1)	5.66	(1)	5	low
SP4	Topsoil	3.8	(1)	26.03	(1)	0.7	(1)	2.92	(1)	4.53	(1)	5	low
	Subsoil	1.5	(1)	24.46	(1)	0.6	(1)	2.37	(1)	5.05	(1)	5	low
SP5	Topsoil	1.5	(1)	16.94	(1)	0.7	(1)	2.67	(1)	3.51	(1)	5	low
	Subsoil	1.9	(1)	8.73	(1)	0.9	(1)	4.07	(1)	7.70	(1)	5	low
SP6	Topsoil	5.5	(1)	5.36	(1)	0.6	(1)	3.07	(1)	6.93	(1)	5	low
	Subsoil	4.5	(1)	26.73	(1)	0.7	(1)	5.17	(1)	4.24	(1)	5	low

A number in blanket is a score of each parameter.

[a]OM (g/kg): <15 = 1, 15-35 = 2; >35 = 3; [b]Avail. P (mg/kg): <10 = 1, 10-25 = 2, >25 = 3; [c]Avail. K (mg/kg): <60 = 1, 60-90 = 2, >90 = 3; [d]CEC ($cmol_c$/kg): <10 = 1, 10-20 = 2, >20 = 3; [e]BS (%): <35 = 1, 35-75 = 2, >75 = 3.

[b]Fertility rating: sum of scores from OM, Avail. P, Avail. K, CEC and BS; <7= low, 8-12 = medium, >13 = high.

Table 4 FCC unit of soils chosen

Profile code	Type	Substrata type	Modifiers				FCC-unit
			d	a	k	e	
KL13	L		+			+	Lde
KD3	L		+	+	+	+	Ldake
NK9	S		+		+	+	Sdake
NP27	S		+			+	Sdae
SP3	S	L	+			+	SLdae
SP4	S	L	+		+	+	SLdke
SP5	L		+		+	+	Ldke
SP6	S		+		+	+	Sdke

S = sandy topsoil: loamy sand and sand; L = loamy topsoil < 35% clay; d = ustic or xeric soil moisture regime: dry > 60 consecutive days/year but moist >180 cumulative days/year within 20 to 60 cm depth; a = >60% Al saturation within 50 cm, or < 33% base saturation of CEC (BS_7) determined by sum of cations at pH 7 within 50 cm, or < 14% base saturation of CEC ($BS_{8.2}$) by sum of cations at pH 8.2 within 50 cm, or pH < 5.5 except in organic soils (O); k = < 10% weatherable minerals in silt and sand fraction within 50 cm, or siliceous mineralogy, or exchangeable K < 0.20 $cmol_c$/kg soil, or exchangeable K < 2% of sum of bases, if sum of bases is < 10

$cmol_c$/kg soil; e = < 4 $cmol_c$/kg soil as ECEC, or < 7 $cmol_c$/kg soil by sum of cations pH 7, or < 10 $cmol_c$/kg soil by sum of cations + Al^{3+}+H^+ at pH 8.21.

Conclusion

Cassava growing soils under different rainfall in northeast Thailand were similarly low fertile in both topsoil and subsoil except for medium fertility level of KD3's topsoil. Genetically, they were deep soils but plough pan that can restrict the growth of cassava was observed in KD3, SP3, SP4 and SP5 pedons. Cassava tuber rot can be experienced in KL13 and NK9 soils as ground water can fluctuate to shallow depths during rainy season. Despite being developed under different amounts of annual rainfall, these soils chosen still experienced moisture deficiency during dry season as rainfall distribution in this period was similarly low. The soils shared rather analogous modifiers in their FCC unit of which 'd,' and 'e' were found in all soils, illustrating the risk of soil moisture shortage and easy loss of soil nutrient by leaching due to their low CEC. However, proportion of NPK fertilizer recommended for growing cassava in these soils varied in accordance with OM, available P and K contents. Continuous application of soil organic amendments at certain rates should be performed to improve soil quality and the efficiency of chemical fertilizer. In the case of cassava growing soils, new modifiers should be introduced to improve interpretability of this fertility classification.

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