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Interpretability Comparison between Soil Taxonomic and Fertility Capability Classification Units: A Case of Some Major Cassava Soils in Northeast Thailand

Somchai Anusontpornperm[1]*, Stephen Nortcliff[2] and Irb Kheoruenromne[1]

ABSTRACT

A comparison between two classification systems in the context of interpretability for soil management recommendations was undertaken on nine soils growing cassava across the northeast region of Thailand. Study methods included field investigation and laboratory analysis, both based on standard methods. Results showed that all soils were classified as Typic Paleustults, based on the Soil Taxonomy system, whereas their fertility capability classification (FCC) was different, mainly in modifiers. The limitation of the Soil Taxonomy system, which provided only a Typic subgroup for use in Paleustults, created a difficulty in interpreting this group of soils for agronomic uses. FCC units tended to be more interpretative and clearly indicated major soil constraints for cropping.

It is strongly recommended that the taxonomy unit of these particular soils needs modification at the subgroup level, in order to distinguish the soils and to offer more meaningful interpretation for guidelines on soil management. Modification of FCC units could also improve the interpretability of the system by adding new modifiers indicating the presence of some soil constraints at the Type or Substrata level to reflect a priority on soil management.

Key words: soil taxonomy, FCC, cassava, soil classification, coarse-textured soils

INTRODUCTION

Thailand has a total area of 51.3 million hectares and the cassava-growing areas occupy 2.47% of the total area of the country; more than 60% of the cassava production areas are located in the Northeast and Southeast Coast regions. The topography in the cassava-producing areas is generally undulating and the soils are mostly Ultisols of loamy sand or sandy loam texture and pH 5.0-6.5. Some of these soils are erosion-prone and most of them have been degraded, due to erosion and long-term intensive cropping. Duangpatra (1988) reported that 90% of cassava-crop soils in Thailand were, based on Soil Taxonomy (1975), classified into Ultisols (75%) and Entisols (15%). Paleustults were the major soils on which cassava was grown, accounting for approximately 67% of the Ultisols. Cassava is considered tolerant to low-fertility conditions and grows well on acid soils where other crops cannot be grown satisfactorily (Howeler, 1981).

[1] Department of Soil Science, Faculty of Agriculture, Kasetsart University, Bangkok 10900, Thailand.
[2] Department of Soil Science, School of Human and Environmental Science (SHES), University of Reading, Whiteknights, Reading RG6 6DW, UK.
* Corresponding author, e-mail: somchai.a@ku.ac.th

The Fertility Capability Soil Classification System (FCC) (Sanchez *et al*., 1982) was developed as an attempt to bridge the gap between the subdisciplines of soil classification and soil fertility (Buol, 1972; Buol and Nicholaides, 1980). As a technical soil classification system, it focuses on specific use of natural soil classification systems, such as Soil Taxonomy (Soil Survey Staff, 1975, 1999) and the World Reference Base for Soil Resources (FAO, 1998), which are essentially records of soil properties. The direct interpretation of the natural system for specific use is difficult because criteria relevant to a specific soil use are confounded with other criteria, since a natural system attempts to organize all the features that can be measured in a soil (Cline, 1949). Natural soil classification systems place more emphasis on the subsurface than on topsoil properties, because of their more permanent nature, whereas most soil management practices are largely limited to the ploughed layer. In the context of Thailand, some soil scientists (Eiumnoh, 1984; Kheoruenromne, 1989; Kheoruenromne *et al*., 1998; Kheoruenromne *et al*., 1999) have tried to use this system to classify soils in comparison with the Soil Taxonomy system in order to produce interpretative soil units that are more specific. It was found that such a system could be quite advantageous for on-site crop production planning.

This study was conducted on some major cassava-crop soils in Northeast Thailand, to compare the interpretability of Soil Taxonomy and FCC units for growing cassava. Recommendations and modifications to the Soil Taxonomy system were made, mainly considering soil management input in order to optimize the yield of this crop.

MATERIALS AND METHODS

The study methods were composed of field investigation and laboratory analysis. Field study included site description and soil morphological identification using pedon analysis based on standard methods (Kheoruenromne, 1987; Soil Survey Division Staff, 1993). The laboratory analysis conducted at the Department of Soil Science, Kasetsart University, Bangkok considered the physical and chemical properties of soil samples collected from the field using standard methods of soil analysis (National Soil Survey Center, 1996). Nine soil profiles were selected, namely Pedons 1 and 2 collected from Khon Kaen province, while Pedons 3, 4, 5 and 6 were from Nakhon Ratchasima province, Pedon 7 from Sakon Nakhon province, Pedon 8 from Mahasarakham province and Pedon 9 from Roi Et province. The FCC used in this study consisted of three levels: type (topsoil texture), substrata type (subsoil texture), and modifiers. Soils in this study were grouped using class designations from the three categorical levels combined to form an FCC-unit of each soil (Sanchez *et al*., 1982; Yost *et al*., 1997), whereas taxonomic units of the same soil would be derived from the latest version of the Soil Taxonomy Classification System (Soil Survey Staff, 1999; 2006).

RESULTS AND DISCUSSION

General information

All soils were very deep and well drained, with the thickness of the surface layer ranging from 21 to 50 cm (Table 1). Their profile development was genetically similar (Ap-Bt) and characterized by the presence of an argillic horizon. A geologic discontinuity and water-logged horizons (Btg) were found in the lower part of Pedon 6 and Pedon 9, respectively. They occupied nearly flat to undulating surfaces with slope ranging from 1 to 7% and occurred on the lower part of the middle terrace or midslope of low hills up to the summit of the landscape. The parent material of these soils was transported, so some soils were underlain by residuum of sandstone, except for Pedon 5 that had siltstone involved.

Table 1 General characteristics of the selected soils collected from Northeast Thailand.

Pedon	Thickness of surface horizon (cm)	Effective depth (cm)	Profile development	Slope (%)	Relief	Physiographic position/drainage	Parent materials
1	21	200+	Ap-Bt1-Bt2-Bt3-Bt4-Bt5-Bt6	6	Undulating	High terrace/well drained	Old alluvium
2	30	200+	Ap-Bt1-Bt2-Bt3-Bt4-Bt5-Bt6	2	Slightly	Middle terrace/well drained	Old alluvium
3	20-30	210+	Ap-Bt1-Bt2-Bt3-Bt4-Bt5-Bt6	5	Undulating	Midslope of low hill/well drained	Wash over residuum derived from sandstone
4	50	200+	Ap1-Ap2-Bt1-Bt2-Bt3-Bt4-Bt5-Bt6	5	Undulating	Shoulder slope of low hill/ well drained	Wash over residuum derived from sandstone
5	33	200+	Ap-Bt1-Bt2-Bt3-Bt4-Bt5-Bt6	7	Undulating	Midslope of low hill/well drained	Wash mixed with local alluvium siltstone mixed with sandstone over residuum derived from siltstone mixed with sandstone
6	30	200+	Ap1-Ap2-Bt1-Bt2-Bt3-2Bt4-2Bt5-2Bt6-2Bt7	2	Slightly	Crest slope of low hill/ well drained	Local alluvium over discontinuity colluvium and residuum of sandstone
7	28	200+	Ap-Bt1-Bt2-Bt3-Bt4-Bt5-Bt6-Bt7	1	Nearly flat	Middle terrace/well drained	Old alluvium
8	43	200+	Ap1-Ap2-Bt1-Bt2-Bt3-Bt4-Bt5-Bt6	3	Undulating	Middle terrace/well drained	Old alluvium
9	33-45	180+	Ap1-Ap2-Bt-Btg1-Btg2-Btg3	2	Slightly undulating	Lower part of middle terrace	Old alluvium

Soil morphology

All soils were generally similar to each other in the context of their morphological characteristics, with the clear exception of color that was influenced by position in the landscape. This was because they had developed from similar parent materials, such as sandstone and siltstone and under broadly similar climatic conditions. The landscape position also produced differences in some of the physical and chemical properties among these soils, which are discussed below. The clay content of these soils typically increased with depth, whereas field soil pH gradually decreased with depth, at least to the middle part of the profiles. The pedons could be subdivided into three groups using their colors: (i) red to dark red with hue value ranging from 10R to 2.5YR (Pedon 1), (ii) yellowish red to reddish yellow or strong brown with hue values ranging from 2.5 or 5YR to 7.5YR (Pedons 2, 3, 4 and 6), and (iii) reddish yellow or strong brown to yellowish brown with hue values ranging from 5 or 7.5YR to 10YR (Pedons 5, 7, 8 and 9). It was clear that the higher the position in the landscape, the redder the color of the soil became.

Physical properties

In this study, the bulk density of the top three layers, determined by the core method, ranged between 1.45 and 1.79 Mg m^{-3} (Table 2).

Table 2 Some physical properties of the selected soils collected from Northeast Thailand.

Pedon	Horizon	Depth (cm)	Bulk density (Mg M^{-3})	Hydraulic conductivity (cm hr^{-1})	Particle size distribution Sand (----------g kg^{-1}----------)	Silt	Clay	Textural class	AWC (%)
1	Ap	0-21	1.63	0.59	835	93	72	Sandy loam	9.8
	Bt1	21-42/52	1.71	1.31	719	82	199	Sandy loam	8.8
	Bt2	52-69	1.48	7.56	705	95	200	Sandy loam	8.5
2	Ap	0-30	1.61	0.44	828	139	34	Loamy sand	11.7
	Bt1	30-50	1.70	0.32	755	139	106	Sandy loam	6.7
	Bt2	50-71	1.60	2.03	708	143	147	Sandy loam	10.4
3	Ap	0-20/30	1.48	10.59	897	85	18	Sand	7.2
	Bt1	30-44	1.60	1.66	900	74	26	Sand	7.0
	Bt2	44-73	1.58	3.23	877	69	54	Loamy sand	6.9
4	Ap1	0-25	1.51	4.92	878	78	44	Sand	7.8
	Ap2	25-50	1.71	0.75	901	69	30	Sand	6.7
	Bt1	50-70	1.67	1.18	843	90	66	Loamy sand	10.4
5	Ap	0-33	1.62	0.14	822	70	108	Loamy sand	6.9
	Bt1	33-60	1.68	0.13	756	60	184	Sandy loam	8.9
	Bt2	60-90	1.53	3.57	805	72	123	Sandy loam	12.0
6	Ap1	0-30	1.60	0.21	839	109	52	Loamy sand	11.4
	Ap2	30-58/64	1.69	0.04	761	126	113	Sandy loam	6.6
	Bt1	64-80	1.45	5.48	835	76	89	Loamy sand	10.8
7	Ap	0-28	1.55	0.27	816	115	69	Loamy sand	16.0
	Bt1	28-46	1.70	0.12	845	83	72	Loamy sand	12.3
	Bt2	46-70	1.56	1.02	765	113	121	Sandy loam	9.0
8	Ap1	0-20	1.56	1.11	877	55	68	Loamy sand	8.9
	Ap2	20-43	1.79	0.05	816	100	84	Loamy sand	11.4
	Bt1	43-65	1.67	0.10	772	90	136	Sandy loam	8.5
9	Ap1	0-33/45	1.47	3.80	861	59	80	Loamy sand	14.7
	Ap2	45-59/66	1.73	0.05	814	50	136	Sandy loam	12.0
	Bt1	66-80/86	1.64	0.04	793	54	153	Sandy loam	17.1

It can be noticed that the highest bulk density value was generally found in a layer directly underlying the soil surface horizon. This dense layer had sharply higher values than did the topsoil and the horizon below it. This was because certain tillage implements, such as 3- and 7-disk harrowing, an operation that was usually repeated 2-3 times for land preparation, might have compacted the soil below their working depth, even as they lifted and loosened the soil above. Use of these implements or repeated trips over the field by heavy machinery could form plough pans or traffic pans, which are dense zones immediately below the ploughed layer.

The trends of hydraulic conductivity values with depth were very similar among these soils. Most soils had the lowest hydraulic conductivity value within 50 cm of the mineral soil surface, and thus were classified as very slow to moderately slow, particularly in the one or two layers directly underneath the topsoil layers. The topsoils of some soils, Pedons 2, 5 and 7, had moderately slow to slow rates of hydraulic conductivity, despite having a high content of sand particles. These low rates were possibly because the structure of the surface horizon had been damaged by soil mismanagement (Bonnet 1968; Lugo-Lopez *et al.*, 1970; Baver *et al.*, 1972; Wilkinson and Aina, 1975; Bridge *et al.*, 1975; Lal, 1976), especially by improper timing of ploughing using heavy tractors.

As all the soils had developed from coarse-textured, sedimentary rock, namely sandstone and siltstone, they all were found to have a coarse-textured particle size throughout the upper three horizons. Sand content of more than 700 g kg^{-1} clearly dominated this proportion of the particle size distribution. As a result, textural classes of these layers were sand, loamy and sandy loam. In addition, the small amount of clay showed a slight increase with depth. The available water capacity values (AWC) of these soils were relatively low and varied among soil profiles from different sites and among horizons within a profile, ranging from 6.6 to 17.1% because sandy soils released more of their water at low suction (Marshall *et al.*, 1996).

Chemical properties

Soil pH values were within the range 4.9 to 6.5 and 4.1 to 6.1 when measured in H_2O and KCl, respectively (Table 3). This indicated acidity (apparently from hydroxy-aluminium and organic functional groups), ordinarily in amounts sufficient to affect acidity-sensitive crops (Buol *et al.*, 2003). Organic matter content of the soils was very low, usually less than 10 g kg^{-1} in the surface layer, while much lower contents were found in the Bt horizon. Nitrogen in these soils also was very low throughout the profiles. Available phosphorus content was generally low, although it was higher in the topsoil than in subsoil, ranging from 0.5 to 27.6 mg kg^{-1} and from 0.3 to 13.6 mg kg^{-1}, respectively. This was quite similar to the pattern of available potassium, which had values from 4.7 to 110.5 mg kg^{-1} in the Ap horizon but decreased in the subsoil within the same soil profile.

In the context of some exchange properties, all of the soils were low in base status, having a sum of bases mostly lower than 2 cmol kg^{-1} even in the topsoil at some sample sites. Extractable calcium was the dominant base in these soils, while potassium had the lowest concentration. Exchangeable acidity values were normally rather high in most soils. With respect to the analytical data, the low base saturation percentage of the soils was directly related to the high value of exchangeable acidity and the low content of bases. In contrast to exchangeable acidity, cation exchange capacity at pH 7 of these soils was low, mostly lower than 5 $cmol_c$ kg^{-1} in the top three layers. The increase in clay content with depth largely resulted in cation exchange capacity that increased with depth in all soils.

Table 3 Soil reaction, organic matter, total nitrogen, available phosphorus and available potassium of selected soils.

Pedon	Horizon	Depth	pH (1:1)		OM	Total N	Avail. P	Avail. K
		(cm)	H_2O	KCl	(-------g kg^{-1} -------)		(-------mg kg^{-1} -------)	
1	Ap	0-21	6.2	5.4	5.3	0.40	16.48	18.5
	Bt1	21-42/52	5.5	4.7	4.7	0.39	13.60	16.2
	Bt2	52-69	5.2	4.3	4.0	0.53	2.44	14.7
2	Ap	0-30	5.9	4.8	3.2	0.21	9.03	14.6
	Bt1	30-50	5.3	4.5	1.3	0.23	1.34	5.5
	Bt2	50-71	4.9	4.1	3.4	0.28	1.10	5.6
3	Ap	0-20/30	6.5	5.7	7.9	0.21	0.83	4.7
	Bt1	30-44	6.6	5.6	2.0	0.14	0.92	10.6
	Bt2	44-73	6.0	4.8	0.6	0.11	0.50	13.2
4	Ap1	0-25	5.9	5.3	6.5	0.37	3.42	13.0
	Ap2	25-50	5.4	4.9	6.5	0.23	2.00	14.2
	Bt1	50-70	5.7	4.7	3.0	0.14	2.17	21.0
5	Ap	0-33	5.8	5.1	10.1	0.34	7.36	91.4
	Bt1	33-60	5.9	4.9	11.0	0.50	2.36	102.4
	Bt2	60-90	5.6	5.0	5.4	0.32	1.09	17.1
6	Ap1	0-30	5.5	4.4	5.0	0.57	6.44	110.5
	Ap2	30-58/64	5.2	4.6	1.9	0.45	0.51	38.3
	Bt1	64-80	5.4	4.5	1.1	0.54	0.25	15.1
7	Ap	0-28	6.2	5.6	9.1	0.55	16.60	79.3
	Bt1	28-46	5.4	5.2	5.2	0.41	2.94	34.6
	Bt2	46-70	4.9	4.5	4.6	0.38	1.85	20.2
8	Ap1	0-20	6.0	5.5	8.7	0.46	24.65	25.7
	Ap2	20-43	6.8	6.1	7.4	0.45	27.61	39.3
	Bt1	43-65	5.9	5.1	5.8	0.41	21.11	34.2
9	Ap1	0-33/45	6.1	4.9	4.7	0.23	83.05	31.3
	Ap2	45-59/66	6.1	4.9	6.7	0.19	31.78	55.9
	Bt1	66-80/86	6.1	4.6	2.6	0.14	35.67	67.3

Taxonomic unit of selected soils

Based on all analytical data, the soils were grouped into Ultisols, due to a presence of an argillic horizon without fragipan, and a base saturation (by sum of cations) of less than 35% at 125 cm below the upper boundary of the argillic horizon or 180 cm below the mineral soil surface, whichever was shallower (Soil Survey Staff, 1999). The southern areas of Northeast Thailand have an ustic soil moisture regime, thus these Ultisols would be classified in the Ustults suborder. At the great group level, it was not possible to distinguish between the soils; hence they were placed into Paleustults, which were diagnosed by a reduction in the relative clay content in the argillic horizon to less than 20% within 150 cm of the surface. Moreover, the version of Soil Taxonomy in Soil Survey Staff (1999) did not provide any alternative subgroups for use in this great group. All nine soils in this study were, therefore, eventually put in the same subgroup, namely Typic Paleustults. As a result, there was a difficulty in interpreting this taxonomic unit and making any recommendations in the context of agricultural uses and for cassava production in particular. However, the soils did have differences in morphological, physical and chemical properties, and the position in the landscape had a direct or indirect impact on soil use. Anusontpornperm *et al*. (2006) presented that these soils had different soil productivity or needed different inputs under certain soil management, by considering the property differences mentioned above. Some subgroups such as Kanhaplic, Psammentic, Udic and Aquic that occur in other great groups in the Soil Taxonomy system could be used to distinguish these soils from each other and subsequently, this could make the newly modified subgroup more meaningful in terms of interpretation for agricultural uses.

FCC unit of selected soils

All of the soils were of S type because of their sandy texture at topsoil layer. A slight increase in the clay content of subsoils in Pedons 1, 2, 5, 6 and 9 caused this group of soils to fall into the "L" Substrata type (Table 4). Some similar modifiers such as "h", "a", "d", "e", "k" and "p" were used to indicate different soil constraints, depending largely upon their chemical properties. In addition, slope range, which was nearly flat to undulating (1-8%), determined the current soil erosion control scheme for cassava production, resulting from a contrast in soil texture between topsoil and subsoil that might accelerate the rate of runoff.

Modification of FCC units in relevant to cassava production

Based on historical yield data retrieved from trials and farmer's fields where these soils were investigated, yield variation was found, not surprisingly, in spite of FCC units varying slightly as shown in Table 4. This would lead to the need for modification of these FCC units in order to improve the interpretability of this system in terms of cassava crops grown on these types of soils. This was because most of the soils were in quite similar FCC units and the soils also shared some major limiting properties for plant growth. This was mainly due to the soils having different kinds and levels of inputs. However, organic matter content, the presence of a root-restricting layer created by improper cultivation and soil erosion susceptibility should be additionally applied to enhance the interpretations using FCC, giving distinct units with differing agronomic interpretations.

Table 4 FCC-units of selected soils.

Site	Type	Substrata type	Modifiers*	FCC-unit
Pedon 1	S	L	Hdek	SLhdek (5-6%)
Pedon 2	S	L	Adek	SLadek (2-4%)
Pedon 3	S	-	Hdekp	Shdekp (4-6%)
Pedon 4	S	-	Hdekp	Shdekp (4-6%)
Pedon 5	S	L	Dep	SLdep (6-8%)
Pedon 6	S	L	Hdep	SLhdep (2-4%)
Pedon 7	S	-	De	Sde (1-2%)
Pedon 8	S	-	Dek	Sdek (2-4%)
Pedon 9	S	L	Hdek	SLhdek (1-2%)

*a and h; base saturation not greater than 12% for "a" modifier and 12-40% for "h" modifier according to Yost *et al*. (1997),
d; ustic soil moisture regime,
e; if "a" or "h" modifier present, CEC pH 7 of less than or equal to 7, otherwise CEC pH of less than 4 (Yost *et al*., 1997),
k; modified from Yost *et al*. (1997) either an "S" type or an "S" substrata type including "L" type, exchangeable potassium of not greater than 0.14 cmol kg^{-1},
p; (low available phosphorus): available P by Bray II extractant less than 8 mg kg^{-1} within 50 cm of the soil surface. This modifier does not exist in either Sanchez *et al*. (1982) or Yost *et al*. (1997) but was used, particularly for Thai soils, in reports by Eiumnoh (1984), Kheoruenromne *et al*. (1998) and Kheoruenromne *et al*. (1999).

Whilst the focus in FCC was on the surface layers because they are considered agronomically important, addressing the capability with respect to cassava might involve an appropriate consideration of deeper layers. For example, bulk density and hydraulic conductivity values of the top three layers can be combined and added to the FCC unit to indicate a compaction zone occurring either at the base of the topsoil or upper subsoils; therefore, priority of soil management can be made accordingly. This can be made by adding the prime (') to the Type or Substrata levels, if this dense layer occurred. Likewise, soil organic matter content, which was believed to be essential for plant growth with respect to both soil physical and chemical properties, must be given more emphasis, although organic matter has been deliberately excluded from this system in the past. However, there was evidence of certain critical organic matter content above which the yield of cassava can be optimised. Using an example from nine locations in four Asian countries to show the relationship and to estimate the 'critical level' of the nutrient or soil parameter, it was found that critical levels were associated with 3.1% organic matter (Howeler, 2002). As a consequence, all soils in this study should have this modifier to indicate low soil organic matter content. Additionally, the range of organic matter content based on an approximate classification of soil chemical characteristics according to the nutritional requirements of cassava, (for instance, very low = <10 g kg^{-1}, low = 1-2 g kg^{-1} and medium = 2-4 g kg^{-1}) can be added to express the variation of soil organic matter among these soils, using an asterisk (*) or two (**) in this case. Subsequently, if an apostrophe (') was affixed to the Type or Substrata level to indicate the presence of an impeded layer or compaction zone within 50 cm from the soil surface and "m" is used as a modifier for organic matter content in the topsoil, the newly modified FCC units of these soils could be, in order from Pedon 1 to 9: SL'hdekm** (5-6%), SL'adekm** (2-4%), S'hdekpm** (4-6%), S'hdekpm** (4-6%), SL'depm* (6-8%), SL'hdepm** (2-4%) S'dem** (1-2%), S'dekm** (2-4%) and SL'hdekm** (1-2%),

CONCLUSION

The interpretation of the FCC units demonstrated a similarity in the context of soil management. The soils were classified as sandy at the Type level, and loamy at the Substrata level in some soils. Modifiers were quite similar, all being predominantly determined by low cation exchange capacity and low organic matter content. Other modifiers showed acidity problems in some soils, but it was not crucial in most soils. The quantity of available potassium was vitally too low in most soils, whereas available phosphorus content was insufficient in some soils. Slope ranges for the sites indicated that the soils occupying undulating terrain were susceptible to soil erosion both because of the slope percentage and inherited soil properties.

Interpretation of the current FCC units to indicate their suitability for growing cassava revealed only small differences in soil management schemes among the soils studied. These differences depended on low quantities of available nutrients, organic matter content, ability to retain plant nutrients against leaching, the need to break up impeding layers and soil erosion control. Modification of FCC units could be made to improve the interpretability of the system, by adding a new modifier for the amount of organic matter content needed to optimize cassava yield and improve the fertility status of the soils in general. Additionally, a symbol indicating the compaction zone could be linked with the Type or Substrata level to reflect the priority on soil management. These FCC units would be useful in this respect because interpretation was difficult due to a lack of differentiation using previous soil taxonomic units, which typed all soils as Typic

Paleustults, although they might be different slightly at the family level. However, the interpretation of FCC units did not show any clear relationship to the soil taxonomic units because cultivation had changed some soil properties, especially in the upper part of soil solum where FCC placed most emphasis. This meant that the FCC system needs further analytical data to facilitate precise classification, which can rarely be achieved from the Soil Taxonomy system's unit information alone. On the other hand, a careful and precise soil survey with a combination of the full range of taxonomic classifiers is likely to be more effective in terms of making an appropriate interpretation for plant growth. This would provide a guide for a modification of the Soil Taxonomy system, if necessary, in the case of these soils.

LITERATURE CITED

Anusontpornperm, S., S. Nortcliff and I. Kheoruenromne. 2006. **Modification at Subgroup Level of Paleustults: A Case of Thai Soils.** Book of Abstract, WSCC 2006, Philadelphia, Pennsylvania.

Baver, L.D., W.H. Gardner and W.R. Gardner 1972. **Soil Physics**. 4th ed. John Wiley and Sons, NY. 498 pp.

Bonnet, J.A. 1968. Relative infiltration rates of Puerto Rican soils. **J. Agric. Univ. Puerto Rico**. 52: 233-240.

Bridge, B.J., S. Boonyoi and U. Arromratana. 1975. Properties affecting water entry in central plain soils. **Thai J. Agri Sci.** 8:177-193.

Buol, S.W. 1972. Fertility capability classification system, pp.45-50. *In* **Agronomic-Economic Research on Tropical Soils.** Annual Report for 1971. Soil Sci. Dept., N.C. State Univ., Raleigh, NC.

Buol, S.W. and J.J. Nicholaides, III. 1980. Constraints to soil fertility evaluation and extraporation of research results, pp.425-438. *In* **Proceeding of the Congress on Priorities for Alleviating Soil-Related Constraints to Food Production in the Tropics.** IRRI, Los Baños, Philippines.

Buol, S.W., R.J. Southard, R.C. Graham and P.A. McDaniel. 2003. **Soil Genesis and Classification.** 5th ed. Iowa State Univ. Press, Ames, Iowa. 494 pp.

Cline, M.G. 1949. Basic principles of soil classification. **Soil Sci.** 67: 81-91.

Duangpatra, P. 1988. Soil and climatic characterization of major cassava growing areas in Thailand, pp.157-184. *In* R.H. Howeler and K. Kawano, (eds.). **Cassava Breeding and Agronomy Research in Asia.** Proceeding of a Workshop held in Thailand, 26-28 October 1987, Bangkok, Thailand.

Eiumnoh, A. 1984. Application of Soil Taxonomy to Fertility Capability Classification of problem soils in the S.E. Coast of Thailand, pp.169-190. *In* **Ecology and Management of Problem Soils in Asia.** FFTC Book Series No. 27. Taipei, Taiwan.

FAO. 1998. **World Reference Base for Soil Resources.** ISSS, ISRIC and FAO, Rome. 172 p.

Howeler, R.H. 1981. **Mineral Nutrition and Fertilization of Cassava (*Manihot esculenta* Crantz).** Centro Internacional De Agricultura Tropical, Cali, Columbia. 52 pp.

Howeler, R.H. 2002. Cassava mineral nutrition and fertilization, pp. 115-147. *In* R.J. Hillcocks, J.M. Thresh and A.C. Bellotti (eds.), **Cassava: Biology, Production and Utilization**. CABI Publishing, CAB International, Oxon, UK.

Kheoruenromne, I. 1987. **Soil Survey Laboratory Manual**. Department of Soil Science, Faculty of Agriculture, Kasetsart University, Bangkok, Thailand. 182 pp.

Kheoruenromne, I. 1989. The Fertility Capability Soil Classification System: application and interpretation for crop production planning, pp.225-249. *In* **IBSRAM Technical Notes**

No. 3. Bangkok, Thailand.

Kheoruenromne, I., A. Suddhiprakarn and P. Kanghae. 1998. Properties, environment and fertility capability of sandy soils in northeast plateau, Thailand. **Kasetsart J. (Nat. Sci.)** 32: 355-373.

Kheoruenromne, I., A. Suddhiprakarn, P. Kanghae and S. Watana. 1999. Properties and fertility capability of sandy soils in southern Thailand. **Thai J. Agric. Sci.** 32(2): 263-280.

Lal, R. 1976. **Soil Erosion Problems on an Alfisol in Western Nigeria and Their Control.** IITA Monograph No. 1. IITA, Ibadan. 206 pp.

Lugo-Lopez, M.A., J. Juarez Jr. and R. Perez-Escolar. 1970. Correlation between the rate of water intake of tropical soils at hourly intervals to the 8th hour. **J. Agric. Univ. Puerto Rico**. 54: 570-575.

Marshall, T.J., J.W. Holmes and C.W. Rose. 1996. **Soil Physics**. 3rd ed. Cambridge University Press, USA. 453 pp.

National Soil Survey Center. 1996. **Soil Survey Laboratory Methods Manual**. Soil Survey Invest. Rept. No 42, Version 3.0. U.S. Dept. of Agr., U.S. Government Printing Office, Washington D.C. 735 pp.

Sanchez, P.A., W. Couto and S.W. Buol. 1982. The Fertility Capability Soil Classification System: interpretation, applicability and modification. **Geoderma** 27: 283-309.

Soil Survey Staff. 1975. **Soil Taxonomy – A Basic System of Soil Classification for Making and Interpreting Soil Survey.** U.S. Dept. Agric., U.S. Govt. Printing Offices, Washington, D.C. 754 pp.

Soil Survey Division Staff. 1993. **Soil Survey Manual.** USDA Handbook No. 18, USDA, Washington DC. 437 pp.

Soil Survey Staff. 1999. **Soil Taxonomy - A Basic System of Soil Classification for Making and Interpreting Soil Surveys.** 2nd ed. USDA., Natural Resources Conservation Service, Washing, DC. 869 pp.

Wilkinson, G.E. and P.O. Aina. 1976. Infiltration of water into Nigerian soil under secondary forest and subsequent arable cropping. **Geoderma** 15:51-59.

Yost, R.S., Z.C. Li, C.S. Smith, J. Benites and F. Nachtergaele. 1997. **Merging Databases and Decision-aids: Linking an Updated Soil Fertility Capability Classification (FCC3) with the WISE (World Inventory of Soil Emission Potentials) Database.** University of Hawaii, Manoa, Hawaii.