Kasetsart J. (Nat. Sci.) 32 : 355 - 373 (1998)

Properties, Environment and Fertility Capability of Sandy Soils in Northeast Plateau, Thailand

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ABSTRACT

A study on properties, environment and fertility capability of sandy soils in Northeast Plateau, Thailand was carried out using nine soil areas as study sites. Field study included pedon analysis and soil environment observation and sampling of soils for laboratory analysis. Laboratory study consisted of physical, chemical, mineralogical and micromorphological analyses of soil samples by standard methods and soil fertility capability determination using a software computer program.

Results of the study revealed that these soils comprise sandy Entisols, sandy Alfisols, sandy Ultisols and coarse-loamy Ultisols on mainly sandy alluvium with generally undulating to flat surface landscape. With the strong influence of sandy parent materials and tropical savanna climate most of the soils even with different profile features show common properties of being acidic, having low natural fertility status and with poor exchange properties. Nevertheless, the soil system still favor cation exchange and their poor fertility can be considered most adversary to crop practices. Fertility capability units of these soils include **Sdaekp**, **Sdhekp** and **SLdhekp** for the upland soils, and **Lgaekp** and **Lghekp** for the lowland ones indicating less serious problem for the lowland soils. Major common constraints for their overall fertility capability are their poor exchange properties (e), low available potassium (k) and phosphorus (p). For the upland sandy soils, in addition to their poor fertility status, the soils have low water holding capacity and with rapid infiltration rate (S) making them very susceptible to moisture deficiency. The lowland soils, however, have good moisture regime for paddy rice with a strong potential for denitrification in anaerobic condition of subsoils (g) during cropping season. General recommendations for management of these soils include split application of complete fertilizer, surface organic matter management, low rate liming and monitoring of potassium availability in cropping practices.

Key words : sandy soils, Northeast Plateau, fertility capability, sandy Entisols, sandy Alfisols, Ultisols.

INTRODUCTION

Northeast Plateau is one of the six physiographic regions in Thailand (Moormann and Rojanasoonthon, 1972). The area has a distinct geology characterized by an extensive region of sandy sedimentary rocks of mainly Triassic period and younger with a limited area of Quaternary alluvium (Department of Mineral Resources, 1982). Salt formation has also been identified to cover a large area in the Plateau making it well known for salt affected and sandy soil problems (Panichapong, 1982). In general, sandy soils in the Northeast Plateau can range from poorly developed to well

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developed ones. These soils, due to pressure of land availability, have been used continually for agricultural production in both upland and lowland situations. Due to their poor properties to support plant growth and their spatial variability, crop production on them has not been very successful and they have been considered problem soils (Kheoruenromne and Suddhiprakarn,1984). This study was carried out to acquire details on sandy soils with the following objectives;

1. To identify characteristic differences of sandy soils and their specific environment,

2. To ascertain the fertility capability of the soils in order to develop improvement measures for agricultural uses.

MATERIALS AND METHODS

Materials

Materials used in the study comprised 1) geologic map of Thailand (scale 1:1,000,000), 2) general soil map of Northeast Thailand (scale 1:500,000), 3) standard soil survey and field sampling kits (Kheoruenromne, 1987), 4) laboratory instruments for physical, chemical, mineralogical and micromorphological analyses of soils inclusive of atomic absorption spectrophotometer (AA), Spectronic 20, X-ray diffractometer, thin section apparatus and polarizing microscope 5) glasswares and chemicals.

Methods

Methods of study conprised field investigation and laboratory analysis. Field investigation emphasized selection of study sites where nine sites were selected. Pedon analysis of soil in a soil pit of $1 \times 2 \times 2$ m (width $\times$ length $\times$ depth) was carried out at each site including sampling of soils for laboratory analysis. At each site environmental parameters were studied and recorded. Laboratory analysis of soil samples was carried out to acquire soil physical and chemical properties, mineralogical component characteristics of soils according to standard laboratory methods and techniques (National Soil Survey Center, 1996). Soil fertility capability classification (Sanchez *et al*., 1982) based on a computer program (basic language) was carried out on data obtained from field investigation and laboratory analyses.

RESULTS AND DISCUSSIONS

Results of the study comprise 1) environmental condition and general characteristics of sandy soils, 2) soil morphology, 3) physical properties of sandy soils, 4) chemical properties of sandy soils, 5) mineralogical characteristics of sandy soils, 6) micromorphology of sandy soils, 7) classification and correlation of sandy soils with existing soil series, and 8) fertility capability of sandy soils.

Environmental condition and general characteristics of sandy soils

General geologic condition of the Northeast Plateau is shown in Figure 1. The area, except for a limit extent of igneous and metamorphic rocks, is underlain by extensive clastic sedimentary rocks (mainly sandstone and siltstone) of Triassic period and younger. Salt formation also occupies the area extensively. Quaternary alluvium can be found only along the river valleys and it is far from being extensive in the region. This geologic condition exerts considerable influence on the general environment and soil properties.

Location of sampling sites are shown in Figure 2. Most of the study sites (sites 1, 3, 4, 6, 7 and 9) are on Quaternary alluvium, whereas sites 2 and 8 are on salt formation and site 5 is on Khok Kruat formation. By the influence of the underlying geology, soils in the area can be generally coarse textured, and some can be with salt effect.

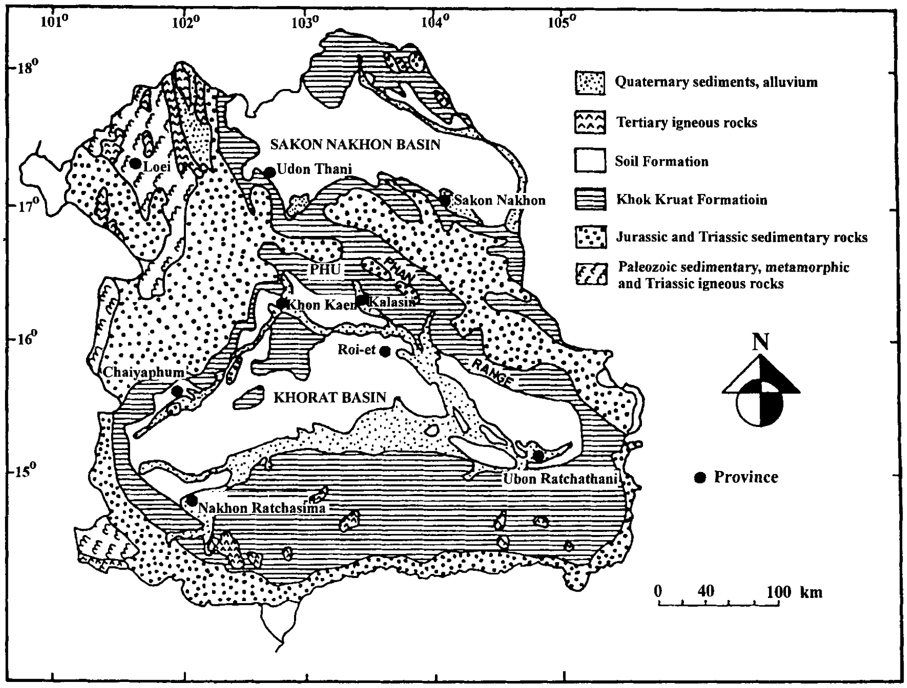

Figure 1 Sketched geologic map of Northeast Plateau, Thailand.

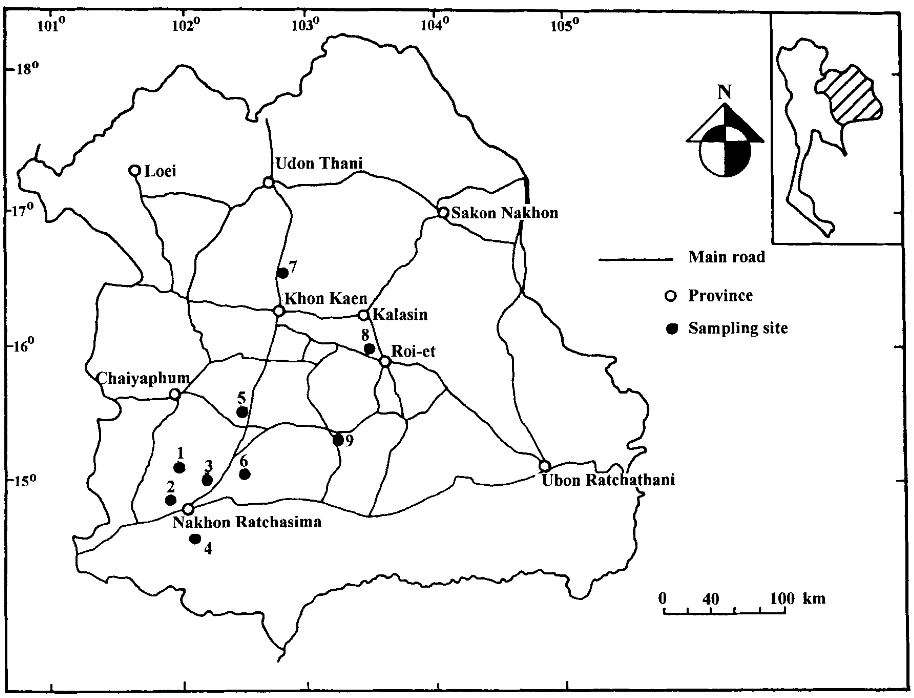

Figure 2 Location map of study sites in Northeast Plateau, Thailand.

Some particular environment and general characteristics of the soil at each site are summarized in Table 1. These soils occupy the areas ranging from 135 m to 200 m above mean sea level and mostly have undulating surface with general slopes ranging from 2 to 3 percent. Prevailing climatic condition of the area is tropical savanna (Aw) (Köppen, 1931) with an evaporation rate exceeding rainfall during dry season for a noticeable period in a year. Most of the study sites have an annual rainfall of 1,100 mm and a mean temperature of 26°C except sites 8 and 9 where the annual rainfall is 1,300 mm and the mean temperature is 27°C. It should be noted here also that rainfall in the study area has not been sufficiently well distributed even during rainy season. Intra-seasonal drought is quite common in the area (Thailand Development Research Institute, 1987).

Results from field investigation indicated that these sandy soils can be found on terrace-like landscape and their terrain features range from depositional to erosional ones. Most of them have an undulating surfaces but their drainage can vary from well drained to poorly drained. These conditions, undoubtedly, can have noticeable influence on their morphology and other properties. Though most of them have moderate permeability and run off, rapid permeability and slow run off

Table 1 General characteristics and environment of sandy soils in Northeast Plateau, Thailand.

Pedon	Thickness of surface soil (cm)	Effective depth (cm)	Drainage	Permeability / Run off	Elevation[1/] / Slope	Surrounding land form	Physiography	Rainfall[2/] / Mean T[3/]
1	25	170+	Moderately well drained	Moderate / Moderate	190 m / 3%	Undulating	Lower part of middle terrace	1,100 / 26
2	25	190+	Well drained	Moderate / Moderate	180 m / 2.5%	Undulating	Upper part of middle terrace	1,100 / 26
3	30	180+	Moderately well drained	Moderate / Moderate	170 m / 3%	Undulating	Lower part of middle terrace	1,100 / 26
4	30	190+	Well drained	Moderate / Moderate	190 m / 2%	Undulating	Upper part of middle terrace	1,100 / 26
5	13	180+	Moderately well drained	Moderate / Slow	200 m / 2%	Slightly Undulating	Lower part of middle terrace	1,100 / 26
6	22	180+	Moderately well drained	Moderate / Slow	160 m / 2.5%	Undulating	Lower part of middle terrace	1,100 / 26
7	20	200+	Well drained	Rapid / Moderate	190 m / 3%	Undulating	Erosional terrace	1,100 / 27
8	21	155+	Poorly drained	Moderate / Slow	140 m / 2%	Flat	Low depositional terrace	1,300 / 27
9	22	200+	Somewhat poorly drained	Moderate / Slow	135 m / 3%	Undulating	Lower erosional terrace	1,300 / 27

1/ Above mean sea level (MSL), 2/ Annual rainfall (mm), 3/ Mean temperature (°C) conditions can be found at some sites. These environmental conditions of landscape and drainage can induce variation in their properties and affect land use in some extent. These soils are very deep soils. Their similar thickness of surface layers clearly indicate land use practices on them (Kheoruenromne and Suddhiprakarn,1984).

Morphology of sandy soils

Profile differentiation of these soils varies. In upland situation their profiles range from an Ap-C type to Ap-Bt type with some having a very thick E horizon. In the lowlands however, Apg-Bg-Btg type of profile can clearly observed as shown in Figure 3. Soil profiles in the lowlands also show contrasting materials in the lower part of the profile illustrated by 2Btg layers. The difference in their profile types, theoretically, is indicative of their development (Buol *et al.*, 1989). Nevertheless, the accumulation of clay in their Bt and 2Btg horizons though sufficient to justify being argillic horizons the clay fraction of these soils is generally small. Aquic condition (Soil Survey Staff, 1996) in these soils can be found in the lower part of a profile (Pedon 7) and in some soils with pronounced lowland environment (Pedons 8 and 9). Profile models as shown in Figure 3 indicate different profile types of these sandy soils. They include Ap-C (Pedon 1), Ap-E-Bt (Pedons 4, 5, and 6), Ap-E-Bt-Btg (P7), Ap-Bt (Pedons 2 and 3) and Apg-Bg-Btg (Pedons 8 and 9). Except the marked contrast on elevation of Pedons 8 and 9 from others, the rest of these soils occupy undulating uplands with only slight difference in the elevation. Their differences, then can be interpreted as being derived from the spatial variation of their parent materials more than from the topographic control of the area.

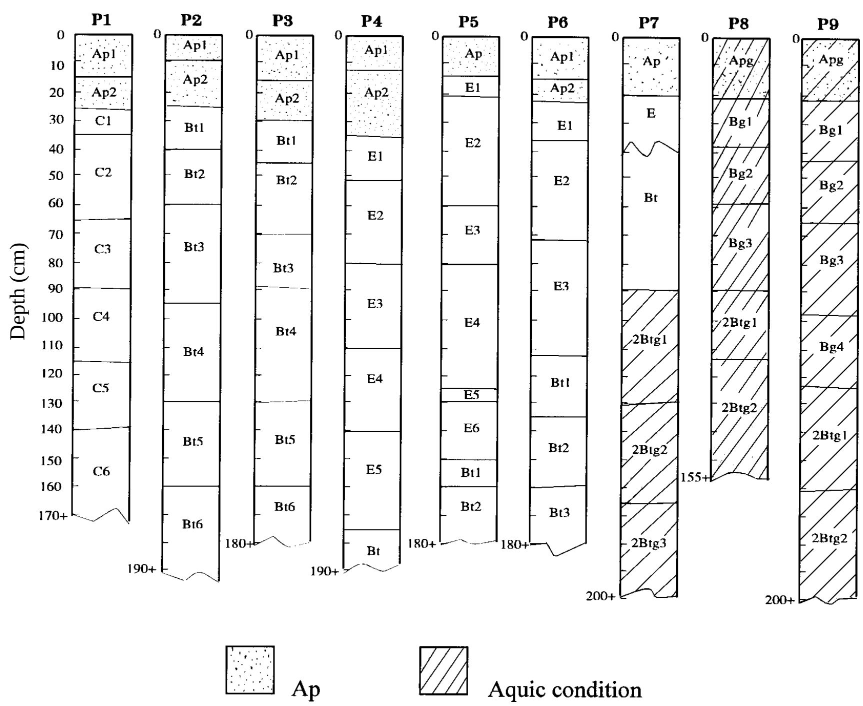

Figure 3 Profile models of sandy soils in Northeast Plateau, Thailand.

Physical properties of sandy soils

Table 2 summarizes some physical properties of sandy soils in Northeast Plateau, Thailand. It is quite clear that most of them have strong sandy texture with generally low to very low clay content even in the clay accumulated (Bt) horizons. Their textural class of surface soils differ only slightly from sand to loamy sand in most cases except for Pedons 8 and 9 that have sandy loam surface texture. Their silt content also shows a certain approximate range in most profiles except for Pedons 6 and 9. This condition suggests influence of parent materials conforming with the results of morphological study previously shown. These soils, in most cases, have bulk density values lower than 1.6 Mg m^{-3}. Except for subsurface layers of Pedons 1 and 2 where bulk density values seem to suggest compaction due to ploughing, other bulk density values do not indicate serious hardpan problem. The marked differences in hydraulic conductivity values of surface and subsurface soils in some soils (Pedons 1, 2, and 5), however, can be the effect of cultural practices in the area. Data in Table 2 also suggest some inverse relationship between saturated hydraulic conductivity values and the amount of silt in these soils. This is common since the silt particles in soils can easily promote the forming of denser layers blocking water percolation (Brady, 1990). Therefore, this aspect of soil physical properties should also be paid attention to for soil management.

Chemical properties of sandy soils

Two groups of soil chemical properties can be recognized. One is a group of properties related closely to plant nutrients in soils and other can be considered as their exchange properties. In this study, the first group is described as basic fertility parameters and the second group is their exchange properties.

Basic fertility parameters of sandy soils

Analytical data on pH, organic matter (OM), total nitrogen (Total N), available phosphorus (Avail. P) and available potassium (Avail. K) are shown in Table 3. Collectively, these sandy soils have relatively low pH values and they are acidic soils (pH $\leq$ 6.5). Their delta pH (ΔpH) values are negative indicating a soil system favoring cation exchange (Sanchez, 1976). All of these soils have very low organic matter content (<10 g kg^{-1}) and total nitrogen ($\leq$0.3 g kg^{-1}). Except for that in the surface layers of Pedons 7 and 8 the values of available phosphorus in these soils can be considered low (<6 mg kg^{-1}) to very low (<3 mg kg^{-1}) and these soils also have low to very low available potassium (<60 mg kg^{-1}). With all of these analytical data it is quite obvious that these soils have low to very low nutrient status for crop cultivation (FAO Project Staff and Land Classification Division, 1973).

Exchange properties of sandy soils

Data related to exchange properties of these sandy soils are summarized in Table 4. In general, these soils have low extractable bases, and in most cases calcium is present in higher amount than the others. Their extractable acidity (EA) values are also relatively low except for values in the lower subsoil of Pedons 6 and 7. The combining effect of low extractable bases and extractable acidity makes their cation exchange capacity values low to very low. These results clearly indicate the poor exchange properties of these soils. The percentage base saturation in these soils varies from low to high and all of them have medium base saturation values (35-75%) in their surface layers. The variability of base saturation values depend strongly on both their base status and extractable acidity. Since the values of both parameters are low the change of values of one parameter can change base saturation values noticeably.

Table 2 Some physical properties of sandy soils in Northeast Thailand.

Depth (cm)	Horizon	Particle size distribution ($g\ kg^{-1}$)[1/] sand	silt	clay	Textural [2/] class	BD[3/] ($Mg\ m^{-3}$)	Ksat.[4/] ($cm\ hr^{-1}$)
Pedon 1 Ustic Quartzipsamment							
0-15	Ap1	907	54	39	S	1.50	6.05
15-25	Ap2	961	11	28	S	1.77	1.00
25-36	C1	900	44	56	S	1.65	1.66
36-65	C2	872	52	76	LS	-	-
65-90	C3	983	79	29	S	-	-
90-115	C4	930	26	44	S	-	-
115-140	C5	913	16	71	S	-	-
140-170+	C6	916	55	29	S	-	-
Pedon 2 Typic Kandiustult							
0-10	Ap1	856	81	63	LS	1.47	7.27
10-25	Ap2	882	75	43	LS	1.76	0.93
25-40	Bt1	823	108	69	LS	1.72	0.53
40-60	Bt2	816	65	119	SL	-	-
60-95	Bt3	764	74	162	SL	-	-
95-130	Bt4	778	58	164	SL	-	-
130-180	Bt5	773	81	146	SL	-	-
180-190+	Bt6	763	127	110	SL	-	-
Pedon 3 Psammentic Haplustalf							
0-15	Ap1	910	44	46	S	1.52	4.32
15-30	Ap2	915	48	37	S	1.52	7.27
30-45	Bt1	893	38	69	S	1.53	4.00
45-70	Bt2	869	30	101	LS	-	-
70-90	Bt3	871	49	80	LS	-	-
90-130	Bt4	851	60	89	LS	-	-
130-160	Bt5	799	51	150	LS	-	-
160-180	Bt6	800	68	132	LS	-	-
Pedon 4 Psammentic Halplustalf							
0-12	Ap1	885	82	33	S	1.68	2.84
12-30	Ap2	868	78	54	LS	1.53	3.26
30-52	E1	876	100	24	S	1.58	1.16
52-80	E2	909	82	9	S	-	-
80-110	E3	885	96	19	S	-	-
110-140	E4	911	81	8	S	-	-
140-175	E5	910	75	15	S	-	-
175-190+	Bt	842	85	73	LS	-	-

Table 2 (cont.).

Depth (cm)	Horizon	Particle size distribution (g kg^{-1})[1/] sand	silt	clay	Textural [2/] class	BD[3/] (Mg m^{-3})	Ksat.[4/] (cm hr^{-1})
Pedon 5 Arenic Haplustalf							
0-13	Ap1	934	38	28	S	1.32	7.38
13-21	E1	924	75	1	S	1.49	1.55
21-60	E2	933	62	5	S	1.46	3.25
60-80	E3	926	57	17	S	-	-
80-125	E4	915	83	2	S	-	-
125-130	E5	941	58	1	S	-	-
130-150	E6	916	39	5	S	-	-
150-160	Bt1	826	69	69	LS	-	-
160-180+	Bt2	829	22	149	SL	-	-
Pedon 6 Arenic Haplustalf							
0-14	Ap1	826	109	65	LS	1.56	0.78
14-22	Ap2	823	175	2	LS	1.56	0.46
22-36	E1	824	175	1	LS	1.42	0.58
36-72	E2	845	143	14	LS	-	-
72-112	E3	829	156	14	LS	-	-
112-135	Bt1	827	132	41	LS	-	-
135-160	Bt2	737	177	86	SL	-	-
160-180+	Bt3	722	194	84	SL	-	-
Pedon 7 Arenic Kandiustalf							
0-20	Ap	822	26	92	LS	1.42	10.41
20-40/45	E	862	58	80	LS	1.45	4.08
45-90	Bt	857	47	96	LS	1.46	-
90-130	2Btg1	721	35	244	SCL	-	-
130-165	2Btg2	652	53	295	SCL	-	-
165-200+	2Btg3	927	50	323	SCL	-	-
Pedon 8 Aeric Kandiaquult							
0-21	Apg	796	84	120	SL	1.38	1.05
21-34	Bg1	809	75	96	LS	1.57	4.39
34-58	Bg2	809	79	112	SL	1.56	-
58-90	Bg3	823	85	92	LS	-	-
90-113	2Btg1	779	93	128	SL	-	-
113-155+	2Btg2	771	73	156	SL	-	-
Pedon 9 Aeric Kandiaquult							
0-22	Apg	677	163	160	SL	1.53	0.48
22-43	Bg1	781	127	92	SL	1.51	1.12
43-65	Bg2	784	120	96	SL	1.55	-
65-98	Bg3	759	149	92	SL	-	-
98-124	Bg4	723	177	100	SL	-	-
124-160	2Btg1	663	185	152	SL	-	-
160-200+	2Btg2	655	169	176	SL	-	-

1/ USDA grading
2/ S = sand, LS = loamy sand, SL = sandy loam, SCL = sand clay loam
3/ Bulk density
4/ Saturated hydraulic conductivity

Table 3 Nutrient status of sandy soils in Northeast Plateau, Thailand.

Depth (cm)	Horizon	pH (1:1) H_2O	pH (1:1) KCl	OM[1/] ($g\ kg^{-1}$)	Total N ($g\ kg^{-1}$)	Avail. P ($mg\ kg^{-1}$)	Avail. K ($mg\ kg^{-1}$)
Pedon 1 Ustic Quartzipsamment							
0-15	Ap1	6.5	3.9	4.4	0.2	2.1	17.7
15-25	Ap2	4.1	3.4	2.7	0.2	1.3	13.5
25-36	C1	4.1	3.4	1.0	0.1	1.3	12.6
36-65	C2	4.1	3.3	1.7	0.1	1.7	10.9
65-90	C3	4.0	3.2	1.5	0.1	1.0	10.0
90-115	C4	4.1	3.3	1.9	0.1	0.9	9.2
115-140	C5	4.2	3.2	1.9	0.1	0.7	9.2
140-170+	C6	4.2	3.3	0.7	<0.1	0.7	7.7
Pedon 2 Typic Kandiustult							
0-10	Ap1	6.0	4.6	4.9	0.2	3.1	53.2
10-25	Ap2	5.5	4.5	0.2	0.1	1.4	19.2
25-40	Bt1	5.5	4.2	1.9	0.1	1.4	16.0
40-60	Bt2	4.6	3.6	0.8	0.1	1.3	15.1
60-95	Bt3	4.2	3.2	2.3	0.1	1.3	23.9
95-130	Bt4	4.2	3.2	1.7	0.1	0.7	23.0
130-180	Bt5	4.1	3.1	0.7	0.1	1.9	19.2
180-190+	Bt6	4.1	3.1	1.7	0.1	0.7	18.5
Pedon 3 Psammentic Haplustalf							
0-15	Ap1	5.5	4.4	8.0	0.2	4.0	12.6
15-30	Ap2	4.7	3.7	5.9	0.2	1.7	12.6
30-45	Bt1	4.4	3.6	1.7	0.2	0.1	7.0
45-70	Bt2	4.4	3.4	2.0	0.1	1.3	8.5
70-90	Bt3	4.3	3.4	1.5	0.1	0.8	9.2
90-130	Bt4	4.3	3.4	2.5	0.1	1.7	8.5
130-160	Bt5	5.1	3.7	2.7	0.1	0.3	10.0
160-180+	Bt6	5.5	4.2	0.2	0.1	0.5	10.0
Pedon 4 Psammentic Halplustalf							
0-12	Ap1	5.8	4.6	6.7	0.2	4.9	33.6
12-30	Ap2	5.5	4.4	5.1	0.2	3.3	16.0
30-52	E1	5.1	4.0	1.0	0.1	3.2	15.1
52-80	E2	4.7	3.7	1.2	<0.1	1.9	10.9
80-110	E3	4.4	3.5	0.3	<0.1	0.8	10.0
110-140	E4	4.5	3.6	0.3	<0.1	0.9	10.0
140-175	E5	4.6	3.6	0.7	<0.1	0.5	9.2
175-190+	Bt	4.2	3.4	1.0	<0.1	0.8	13.5

Table 3 (cont.).

Depth (cm)	Horizon	pH (1:1) H_2O	pH (1:1) KCl	OM[1/] ($g\ kg^{-1}$)	Total N ($g\ kg^{-1}$)	Avail. P ($mg\ kg^{-1}$)	Avail. K ($mg\ kg^{-1}$)
Pedon 5 Arenic Haplustalf							
0-13	Ap	5.3	4.7	4.1	0.1	2.8	23.0
13-21	E1	4.9	3.9	1.7	0.1	4.2	9.2
21-60	E2	5.6	4.7	0.2	<0.1	0.7	7.7
60-80	E3	6.5	5.8	0.3	<0.1	0.8	7.0
80-125	E4	6.2	4.5	0.3	<0.1	2.0	7.0
125-130	E5	6.0	4.4	0.3	<0.1	0.8	6.0
130-150	E6	5.0	3.8	1.4	<0.1	0.9	7.7
150-160	Bt2	4.5	3.4	0.7	0.1	1.0	24.8
160-180+	Bt3	4.4	3.3	2.2	0.1	1.3	40.9
Pedon 6 Arenic Haplustalf							
0-14	Ap1	5.3	4.5	5.9	0.1	2.1	43.2
14-22	Ap2	5.1	4.0	4.2	0.2	0.8	23.0
22-36	E1	4.8	3.6	2.3	0.2	0.8	17.7
36-72	E2	4.4	3.3	1.5	0.1	0.8	14.3
72-112	E3	4.2	3.2	1.2	0.1	0.8	18.5
112-135	Bt1	4.1	3.1	1.7	0.1	0.7	17.7
135-160	Bt2	4.0	3.0	2.7	0.1	1.6	22.2
160-180+	Bt3	4.0	3.0	3.2	0.3	2.0	16.9
Pedon 7 Arenic Kandiustalf							
0-20	Ap	5.7	4.6	1.9	0.2	7.0	19.2
20-40/45	E	5.7	4.2	0.3	<0.1	0.5	10.2
45-90	Bt	5.4	4.0	0.1	<0.1	1.2	10.8
0-130	2Btg1	4.8	3.7	0.3	0.3	0.5	32.5
130-165	2Btg2	5.1	3.8	1.0	0.1	<0.1	32.9
165-200+	2Btg3	5.1	3.8	1.4	0.2	0.1	27.0
Pedon 8 Aeric Kandiaquult							
0-21	Apg	4.9	4.1	4.8	0.5	6.6	15.1
21-34	Bg1	4.9	4.2	0.5	0.2	2.0	12.0
34-58	Bg2	5.0	4.2	0.6	0.1	1.0	10.5
58-90	Bg3	5.5	4.5	<0.1	0.1	0.5	12.1
90-113	2Btg1	5.1	4.0	0.4	0.2	1.9	22.2
113-155+	2Btg2	4.6	3.7	0.3	0.2	0.4	20.4
Pedon 9 Aeric Kandiaquult							
0-22	Apg	5.7	4.3	1.2	0.1	0.2	7.2
22-43	Bg1	5.4	4.3	0.3	0.1	0.6	6.1
43-65	Bg2	5.3	4.4	0.4	0.1	0.2	7.6
65-98	Bg3	5.0	4.3	0.4	0.1	<0.1	7.1
98-124	Bg4	4.9	3.7	0.4	0.1	<0.1	8.0
124-160	2Btg1	4.9	3.6	0.3	<0.1	0.1	9.3
160-200+	2Btg2	4.9	3.6	0.3	<0.1	0.1	11.1

1/ organic matter

Table 4 Exchange properties of sandy soils in Northeast Plateau, Thailand.

Depth	Horizon	Extractable bases				Sum[1/]	EA[2/]	CEC		PBS[4/]
(cm)		Ca	Mg	Na	K	bases		by sum[3/]	NH_4OAc	(%)
		cmol kg^{-1}								
Pedon 1 Ustic Quartzipsamment										
0-15	Ap1	0.80	0.20	0.30	0.10	1.40	1.32	2.72	0.90	52
15-25	Ap2	0.40	0.10	0.30	0.04	0.84	0.92	1.76	0.90	47
25-36	C1	0.30	0.10	0.30	0.03	0.73	1.24	1.97	0.90	37
36-65	C2	0.40	0.10	0.30	0.03	0.83	1.77	2.60	1.80	31
65-90	C3	0.30	0.10	0.20	0.03	0.63	2.15	2.78	1.70	21
90-115	C4	0.20	0.10	0.20	0.03	0.53	1.50	2.03	0.80	25
115-140	C5	0.30	0.30	0.20	0.03	0.83	1.77	2.60	1.40	31
140-170+	C6	0.20	0.20	0.20	0.02	0.62	0.35	0.97	0.80	60
Pedon 2 Typic Kandiustult										
0-10	Ap1	0.80	0.40	0.20	0.10	1.50	0.69	2.19	1.70	68
10-25	Ap2	1.30	0.40	0.30	0.10	2.10	0.52	2.62	1.40	81
25-40	Bt1	0.90	0.30	0.30	0.04	1.54	1.46	3.00	1.20	50
40-60	Bt2	0.90	0.20	0.30	0.04	1.44	0.69	2.13	1.30	67
60-95	Bt3	0.30	0.40	0.30	0.10	1.10	1.25	2.35	1.30	46
95-130	Bt4	0.20	0.40	0.20	0.10	0.90	4.56	5.46	2.70	16
130-180	Bt5	0.30	0.20	0.30	0.10	0.90	2.95	3.85	2.80	23
180-190+	Bt6	0.30	0.20	0.20	0.10	0.90	3.06	3.96	3.00	23
Pedon 3 Psammentic Haplustalf										
0-15	Ap1	1.30	0.40	0.30	0.10	2.10	1.77	3.87	2.60	54
15-30	Ap2	0.70	0.20	0.30	0.04	1.24	1.77	3.01	2.50	40
30-45	Bt1	0.60	0.20	0.20	0.02	1.02	0.62	1.64	1.20	63
45-70	Bt2	0.80	0.30	0.20	0.03	1.32	1.77	3.09	2.30	42
70-90	Bt3	0.50	0.30	0.20	0.03	1.03	1.86	2.89	2.10	34
90-130	Bt4	0.60	0.50	0.20	0.03	1.33	1.89	3.22	2.70	41
130-160	Bt5	2.70	0.70	1.90	0.03	5.33	2.59	7.92	5.20	67
160-180+	Bt6	2.30	0.70	2.60	0.03	5.63	0.95	6.58	5.00	85
Pedon 4 Psammentic Halplustalf										
0-12	Ap1	1.00	0.60	0.20	0.10	1.90	1.38	3.28	2.00	58
12-30	Ap2	1.00	0.50	0.20	0.10	1.80	1.46	3.26	1.70	55
30-52	E1	0.20	0.40	0.30	0.04	0.94	0.36	1.30	0.60	69
52-80	E2	0.10	0.20	0.20	0.03	0.53	0.19	0.72	0.60	71
80-110	E3	0.20	0.10	0.30	0.04	0.64	0.33	0.97	0.60	67
110-140	E4	0.20	0.10	0.20	0.02	0.52	0.38	0.90	0.30	56
140-175	E5	0.30	0.10	0.20	0.02	0.62	0.19	0.81	0.30	75
175-190+	Bt	0.40	0.20	0.20	0.04	0.84	0.62	1.46	1.20	57
Pedon 5 Arenic Haplustalf										
0-13	Ap	0.80	0.40	0.30	0.10	1.60	0.89	2.49	1.40	64
13-21	E1	0.40	0.10	0.30	0.03	0.83	0.14	0.97	0.60	89
21-60	E2	0.30	0.10	0.30	0.03	0.73	0.07	0.80	0.20	88
60-80	E3	0.30	0.10	0.30	0.02	0.72	0.07	0.79	0.30	88
80-125	E4	0.30	0.10	0.30	0.02	0.72	0.14	0.86	0.50	88
125-130	E5	0.30	0.10	0.30	0.02	0.72	0.14	0.86	0.30	88
130-150	E6	0.30	0.10	0.20	0.02	0.62	0.11	0.73	0.40	86
150-160	Bt1	0.80	0.40	0.30	0.01	1.60	0.63	2.23	2.00	73
160-180+	Bt2	1.20	0.60	0.30	0.01	2.20	2.29	4.49	3.30	49

Table 4 (cont.).

Depth (cm)	Horizon	Extractable bases Ca	Mg	Na	K	Sum[1/] bases	EA[2/]	CEC by sum[3/]	CEC NH_4OAc	PBS[4/] (%)
		cmol kg^{-1}								
Pedon 6 Arenic Haplustalf										
0-14	Ap1	2.20	0.40	0.40	0.10	3.10	1.53	4.63	3.30	67
14-22	Ap2	1.50	0.40	0.20	0.10	2.20	1.07	3.27	2.40	67
22-36	E1	0.90	0.30	0.40	0.10	1.70	0.77	2.47	2.00	68
36-72	E2	0.30	0.20	0.20	0.03	0.70	1.11	1.81	1.30	39
72-112	E3	0.60	0.30	0.30	0.10	1.30	1.53	2.83	1.00	46
112-135	Bt1	0.70	0.20	0.30	0.04	1.20	105	2.25	1.70	52
135-160	Bt2	2.70	0.90	0.40	0.10	4.10	3.84	7.94	5.40	52
160-180+	Bt3	3.40	1.10	0.30	0.04	4.80	3.20	8.00	6.50	60
Pedon 7 Arenic Kandiustalf										
0-20	Ap	0.74	0.17	0.31	0.04	1.26	2.00	3.26	0.92	39
20-40/45	E	0.30	0.08	0.31	0.03	0.72	1.50	2.22	0.31	32
45-90	Bt	0.26	0.08	0.37	0.03	0.74	1.00	1.74	0.39	42
90-130	2Btg1	0.94	1.14	0.47	0.08	2.63	2.50	5.13	2.64	51
130-165	2Btg2	1.62	1.52	0.32	0.07	3.53	4.00	7.53	3.71	47
165-200+	2Btg3	1.76	1.77	0.28	0.05	3.87	4.50	8.37	3.74	46
Pedon 8 Aeric Kandiaquult										
0-21	Apg	0.80	0.12	0.33	0.03	1.27	1.50	2.77	1.56	46
21-34	Bg1	0.26	0.04	0.23	0.02	0.56	3.00	3.65	0.46	16
34-58	Bg2	0.38	0.07	0.21	0.04	0.72	1.00	1.72	0.62	41
58-90	Bg3	0.38	0.08	0.39	0.03	0.89	0.50	1.39	0.63	64
90-113	2Btg1	0.70	0.19	0.24	0.04	1.17	1.00	2.17	1.15	54
113-155+	2Btg2	0.49	0.14	0.34	0.01	0.99	2.00	2.99	1.32	33
Pedon 9 Aeric Kandiaquult										
0-22	Apg	0.31	0.05	0.26	0.02	0.64	0.50	1.14	0.93	56
22-43	Bg1	0.32	0.04	0.31	0.02	0.68	0.50	1.18	0.47	58
43-65	Bg2	0.34	0.04	0.27	0.02	0.68	1.00	1.68	0.46	40
65-98	Bg3	0.28	0.05	0.33	0.02	0.68	0.50	1.18	0.93	57
98-124	Bg4	0.50	0.14	0.25	0.02	0.91	0.50	1.41	1.55	64
124-160	2Btg1	0.31	0.08	0.36	0.02	0.78	2.50	3.28	2.02	24
160-200+	2Btg2	0.24	0.04	0.38	0.03	0.68	2.50	3.18	1.86	21

1/ Sum of extractable bases (Ca+Mg+Na+K)

2/ Extractable acidity

3/ Sum of extractable bases + extractable acidity

4/ Percentage base saturation = $\left[\dfrac{Ca + Mg + Na + K}{(Ca + Mg + Na + K) + EA}\right] \times 100$

Data in Tables 3 and 4 suggest that acidity and exchange properties in these soils are less adversary to their fertility for crop production than their low to very low amount of major nutrients and organic matter are.

Mineralogical characteristics of sandy soils

Mineralogical data of these soils as shown in Table 5 support the general synthesis on their chemical properties quite strongly. Their major mineral in the whole soil complex is quartz. Some weatherable minerals (Soil Survey Staff, 1996) such as feldspar and mica are present in silt fraction of only few of them and in a very low amount. Their clay fraction, which is generally small, comprises mainly and consistently kaolinite and quartz. This condition does not promote their exchange properties. Nevertheless, the presence of illite, smectite and some other minerals in their clay fraction still indicates a condition within these soils to favor cation exchange (Uehara and Gillman, 1981). This also influences the high base saturation of some layers in these soils.

Micromorphology of sandy soils

Results from petrographic analysis of soil fabric (Brewer, 1964) indicate subround quartz grains as predominant skeleton materials, and with some runi-quartz suggesting short distance transportation by water of soil parent materials (Michael, 1981). Other resistant minerals found include very limited amount of epidote and tourmaline. Fabric types of these soils comprise porphyroskelic, granular-sepic, vosepic and gefuric plasmic fabrics. Pedological features in the soils are mainly chert and iron-oxide nodules in limited amount. Pores are generally packing voids with some vughs. Clay coats can be found sufficiently in their Bt horizons to be justified as argillic horizons (Soil Survey Staff, 1996). The illuvial clay in these soils can be identified as mainly kaolinite. The micromorphological characteristics of these soils correlate well with field morphology and other soil properties.

Classification and correlation of sandy soils

Based on their morphology, physical and chemical properties and mineralogical characteristics these soils can be placed into taxonomic classes of three orders including Entisols, Alfisols and Ultisols. Pedon 1 is an Ustic Quartzipsamment; siliceous, isohyperthermic. Pedons 3 and 4 are Psammentic Haplustalfs; siliceous, isohyperthermic. Pedons 5 and 6 are Arenic Haplustalfs; sandy, siliceous, isohyperthermic. Pedon 7 is an Arenic Kandiustalf; sandy, siliceous, isohyperthermic. Pedon 2 is an Typic Kandiustult; coarse-loamy, siliceous, isohyperthermic. Pedons 8 and 9 are Aeric Kandiaquults, coarse-loamy, siliceous, isohyperthermic (Soil Survey Staff, 1996). Generalization based on their classification indicates their similarity in poor fertility status affected by their texture and mineralogical characteristics. The influence of their parent materials is quite strong even though their stage of development and their other specific environments vary. These soils can be correlated with some established soil series and variants in the Northeast and other part of Thailand. Pedon 1 is Nam Phong series (Ng). Pedon 2 is San Pa Tong series (Sp). Pedons 3-7 are sandy variants of Korat series (Kt-s). Pedons 8 and 9 are coarse loamy variants of Roi Et series (Re-col) (Kheoruenromne, 1991)

Fertility capability of sandy soils

To evaluate soil fertility capability, a defined set of physical, chemical and mineralogical properties of soils within a depth of 50 centimeters from surface soil are used (Kheoruenromne, 1989; Sanchez *et al.*, 1982). This set of soil parameters is shown in Table 6. It includes broad-grouped texture

Table 5 Mineralogical characteristics of sandy soils in Northeast Plateau, Thailand.

Depth (cm)	Horizon	Clay fraction 1/							Silt fraction 1/			
		Kao.	Ill.	Smec.	Ver.	Chl.	Qtz.	Others 2/	Qtz.	Feld	Mica	Others 3/
Pedon 1 Ustic Quartzipsamment												
0-15	Ap1	x	tr	x	-	-	xx	-	xxxx	-	-	-
36-65	C2	x	tr	x	-	-	xx	tr	xxxx	-	-	-
90-115	C4	x	tr	x	-	-	xx	tr	xxxx	-	-	-
Pedon 2 Typic Kandiustult												
0-10	Ap1	xx	-	-	-	-	xx	-	xxxx	-	-	-
40-60	Bt2	xx	tr	-	-	-	xx	tr	xxxx	-	-	-
95-130	Bt4	xxx	tr	-	-	-	tr	tr	xxxx	-	-	-
Pedon 3 Psammentic Haplustalf												
0-15	Ap1	x	-	-	-	tr	xx	-	xxxx	tr	-	-
45-70	Bt2	xxx	-	-	-	-	x	-	xxxx	-	-	-
90-130	Bt4	xxx	-	-	x	-	x	-	xxxx	-	-	-
Pedon 4 Psammentic Haplustalf												
0-12	Ap1	x	-	-	-	-	xx	tr	xxxx	-	-	-
52-80	E2	x	tr	-	-	-	xxx	tr	xxxx	-	-	-
110-140	E4	x	tr	-	-	-	xxxx	tr	xxxx	-	-	-
Pedon 5 Arenic Haplustalf												
0-13	Ap	xx	tr	-	-	-	xx	tr	xxxx	-	-	-
21-60	E2	x	-	-	-	-	xx	-	xxxx	-	-	-
80-125	E4	x	tr	-	-	-	xx	-	xxxx	-	-	tr
Pedon 6 Arenic Haplustalf												
0-14	Ap1	x	-	xxx	-	-	tr	-	xxxx	-	-	-
36-72	E2	tr	-	xxx	-	-	xx	-	xxxx	-	-	-
112-135	Bt1	x	-	xxxx	-	-	x	-	xxxx	-	-	tr
Pedon 7 Arenic Kandiustalf												
0-20	Ap	xx		tr	-	-	xx	-	xxxx	-	tr	x
45-90	Bt	xx	tr	-	tr	tr	xxx	-	xxxx	-	tr	x
90-130	2Btg1	xxxx	tr	tr	-	tr	tr	-	xxxx	-	tr	x
Pedon 8 Aeric Kandiaquult												
0-21	Apg	xx	-	x	-	-	x	-	xxxx	-	tr	x
34-58	Bg1	xx	-	x	-	-	x	-	xxxx	-	tr	x
90-113	2Btg1	xxx	tr	x	-	-	x	-	xxxx	-	tr	x
Pedon 9 Aeric Kandiaquult												
0-22	Apg	x	-	tr	-	-	xx	-	xxxx	-	tr	x
43-65	Bg2	x	-	tr	-	-	xx	-	xxxx	-	tr	x
98-124	Bg4	x	tr	x	-	-	x	-	xxxx	-	tr	x

1/ xxxx = Dominant (>60%), xxx = Large (40-60%), xx = Moderate (20-40%)
x = Small (5-20%), tr = Trace (<5%), - = Not detected in sample
Kao. = Kaolinite, Ill. = Illite, Smec. = Smectite, Ver. = Vermiculite
Chl. = Chlorite, Qtz. = Quartz, Feld. = Feldspar

2/ Mostly interstratified 1 and 1.4 nm clays except 1.4 nm clays in Pedons 2 and 5

3/ Mainly 0.7nm clay except anatase in Pedons 5 and 6 and some trace of hematite additional to O.7 nm clay in Bg4 of Pedon 9 of surface (Ap) and subsurface soils, critical analytical values of soils, and some distinct soil morphological characteristics indicative of particular soil environment. Based on soil data in Tables 2 to 5, only some of parameters indicated in Table 6 are relevant for determining fertility capability of these sandy soils. A computer program in basic language was used to enter relevant soil data. The data analysis results on fertility capability for each soil and relavant basic suggestions are summarized in Table 7.

These nine soils can be grouped into five fertility capability classification (FCC) units. Pedons 1, 3 and 6 are in **Sdaekp** of which their low water holding capacity, low pH, poor ability to retain nutrients against leaching and low fertility status are major constraints for cropping. Pedons 4, 5 and 7 are in **Sdhekp** and their general constraints

Table 6 Indicative soil parameters used in determination of soil fertility capability (from surface 50-60 cm depth).

Parameters	Soil characteristics/Properties	Symbols[1/]
Type	Broad group of surface soil texture	G, S, L, C, O
Substrata Type	Broad group of subsurface soil texture	G, S, L, C, O
Modifiers	1. Aluminum toxicity (pH in 1:1 H_2O <5.0)	a
	2. Basic reaction (pH in 1:1 H_2O >7.3)	b
	3. Cat clay (presence of jarosite with pH in 1:1 H_2O <3.5)	c
	4. Dry (soil has ustic, aridic or xeric moisture regime)	d
	5. Low cation exchange capacity (sum of bases extracted by NH_4OAc <7 cmol kg^{-1})	e
	6. Gleying (soil color with low chroma (≤2)	g
	7. Acid (pH in 1:1 H_2O = 5.0-6.0)	h
	8. High-P fixation with iron (soil has more than 35% clay and has a color of 7.5 YR or redder, with granular structure)	i
	9. Low K reserve (soil has weatherable minerals <10% in silt fraction)	k
	10. Natric (exchangeable sodium percentage 15%)	n
	11. Low available P (Avail.P (Bray II) <8 mg kg^{-1})	p
	12. Salinity (EC ≥4 dSm^{-1})	s
	13. Vertisols (soil has >35 % clay and more than 50% of clay is smectite)	v
	14. X-ray amorphous (used only when soil has pH >10 in 1N NaF or soil developed on volcanic ash)	x
	15. Slope (slope limitation indicated by slope range)	%
	16. Prime (-’) (indicates amount of gravels by volume in subsurface soil, (-’) gravel 15-35%, (-’’) gravel >35%)	-’ -’’

1/ G = gravelly, S = sandy, L = loamy, C = clayey, O = organic

Table 7 Fertility capability of sandy soils in Northeast Plateau, Thailand.

FCC unit	Soils	Basic interpretations/Suggestions for management
Sdaekp	Pedon 1 (Ustic Quartzipsamment) Pedon 3 (Psammentic Haplustalf) Pedon 6 (Arenic Haplustalf)	Soils have high rate of infiltration and low water holding capacity with moisture limitation for cropping; plants sensitive to A1-toxicity will be affected; low ability to retain nutrients against leaching with potential danger of over liming; low available P and low ability to supply K / Irrigation; split application of complete fertilizer; K availability monitoring and precautionary measure on liming.
Sdhekp	Pedon 4 (Psammentic Haplustalf) Pedon 5 (Arenic Haplustalf) Pedon 7 (Arenic Kandiustalf)	Similar to **Sdaekp** except for the less severity of A1-toxicity / Suggestions for management are generally similar to that of **Sdaekp.**
SLdhekp	Pedon 2 (Typic Kandiustult)	Soil has high to medium rate of infiltration and good water holding capacity in the subsurface and with moisture limitation for cropping; plants very sensitive to A1-toxicity will be affected; low ability to retain nutrients against leaching with potential danger of over liming; low available P and low ability to supply K / Irrigation but with less intensity than that of **Sd** condition, other suggestions for management are generally the same.
Lgaekp	Pedon 8 (Aeric Kandiaquult)	Soil has medium rate of infiltration and good water holding capacity; denitrification frequently occurs in anaerobic subsoil; tillage operation and certain crops may be adversely affected by excess rain, good soil moisture regime for rice cultivation; plants sensitive to A1-toxicity will be affected; low ability to retain nutrients against leaching with potential danger of over liming; low available P and low ability to supply K / Drainage is required for some crops; K availability monitoring and precaution on liming.
Lghekp	Pedon 9 (Aeric Kandiaquult)	Similar to **Lgaekp** except for the less severity of A1-toxicity / Suggestions for management are generally similar to that of **Lgaekp.**

for cropping are similar to those of Pedons 1, 3 and 6. However, this group has less problem with their pH linking to less problem with Al-toxicity in the soils. Pedon 2 is in **SLdhekp** where its water holding capacity is better than that of the two units previously mentioned. Its moisture limitation is slightly less, but its other properties are generally the same with that of the more sandy ones.

Pedons 8 and 9 can be classed into **Lgaekp** and **Lghekp** respectively. Their general constraints for cropping include the long period of water saturation inducing anaerobic condition and denitrification in subsoil of the major root zone, their low ability to retain nutrients, their poor fertility status and acidic condition within the soils. However, Pedon 8 has a more serious condition of acidity and Al-toxicity than Pedon 9 does. Therefore, Pedon 9 should be more easily to manage. Results of the soil fertility capability determination indicate two major aspects of these sandy soils. Firstly, the results demonstrate their poor physical environment through their high rate of infiltration and low water holding capacity particularly under tropical savanna climate. This is quite devastating since moisture is limited for upland cropping and irrigation needs large amount of water to suffice the need for successful cropping. Secondly, their poor fertility status and low ability to retain nutrients are major chemical properties adversary for any type of cropping on them. Soil and fertilizer management need be intensive with high input and continuous attention. Extensive practices cannot be easily effective, particularly for upland cropping. Adding to these limitations is their variable acidity problem. This should also be taken into account though its seriousness is secondary.

For the lowland situation of these soils, even with less physical problems related to water holding capacity and moisture limitation, their basic fertility and their low ability to retain nutrients against leaching are still serious. To develop a successful soil management scheme a basic complete fertilizer application is prime important. For both upland and lowland conditions organic matter management is advised to alleviate physico-chemical properties of these soils.

At present, these sandy soils have been used for cultivation of economic crops. Most of the upland soils are under cassava (Pedons 1, 2, 3, 4, 6). Pedon 5 is planted to sugarcane and Pedon 7 is under mixed cropping of bamboo (*Dendrocalamus asper* Back.) and cassava. Pedons 8 and 9 are under paddy rice (transplanted rice). All of the upland crops indicated are essentially drought-tolerant species and rice yield in these soil areas is generally poor.

CONCLUSIONS

Results of this study revealed that sandy soils in Northeast Plateau, Thailand include Ustic Quartzipsamments, Psammentic Haplustalfs, Arenic Haplustalfs, Arenic Kandiustalfs, and coarse-loamy family of Typic Kandiustults and Aeric Kandiaquults. All of them have siliceous mineralogy family. These soils, particularly the upland ones show both poor physical properties and chemical properties for crop cultivation. For the lowland ones that have coarse-loamy particle size class their chemical properties relating to soil fertility are more adversary to crop practice than that of their physical properties. Major controlling factors for their poor properties are derived mainly from their sandy parent materials and the tropical savanna climatic environment inducing poor nutrient retention capacity and moisture deficiency within the soils. Fertility capability determination results indicate that Ustic Quartzipsamment (Pedon 1), Psammentic Haplustalfs (Pedons 3 and 4), Arenic Haplustalfs (Pedons 5 and 6) and Arenic Kandiustalf (Pedon 7) can either be in Sdaekp or Sdhekp unit depending on their pH. The finer textured ones including Typic Kandiustult (Pedon 2), Aeric Kandiaquult (Pedon 8) and Aeric Kandiaquult (Pedon 9) are in SLdhekp, Lgaekp and Lghekp units respectively. For the upland soils with pronounced sandy texture their common adversary properties for upland crop cultivation include their high rate of water infiltration and low water holding capacity with moisture limitation for cropping, low ability to retain nutrients against leaching, low available potassium and phosphorus. Their difference in pH values suggests the different risk levels on Al-toxicity for sensitive crops. For the lowland soils with finer texture their common properties affecting crop cultivation include the poor condition to be used for upland crops being due to their potential for losing nitrogen by denitrification induced by water saturation of subsoil. Recommendations for their basic management fertility generally include split application of complete fertilizer, soil surface organic matter management, low rate liming and monitoring of potassium availability.

ACKNOWLEDGEMENT

This study is a part of the main research project on Properties and Fertility Capability of Sandy Soils under Kasetsart University Research Grant provided through Kasetsart University Research and Development Institute (KURDI).

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Received date : 17/12/97
Accepted date : 14/05/98