CAPABILITY CONSIDERATIONS FOR TROPICAL SOILS

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Introduction

Tropical environments are by no means homogeneous, nor are tropical soils. Even with respect to climate, the tropics may be differentiated into several subregions in accordance with elevation, temperature and rainfall regimes (Kyuma, 1972). Here, therefore, we have to confine our discussion to low altitude, humid to seasonally dry tropics, because of their relatively high potentials in agriculture.

As for soils, they are even more complex, ranging from very juvenile soils with high fertility to very senile soils almost devoid of fertility. But if we look at a very broad, general picture, the most significant subdivision of tropical soils may be obtained by differentiating soils into those in the upland as against those in the lowland.

Relevant data are cited for tropical Asia which encompasses the areas extending to the east of the Indus and to the south of China, including insular Southeast Asia, and satisfies mostly the climatic conditions as set above. According to 1977 FAO Production Yearbook, the rice land area in tropical Asia was 86,553 x 10^3 ha, producing 171,101 x 10^3 ton of paddy, whereas the area cropped to cereals other than rice was nearly the same as the rice area, 81,602 x 10^3 ha, but production was only 79,614 x 10^3 ton. As the rice land area occurs mostly on lowlands, the above data tell us that a unit area on lowlands produced twice as much grains as that on uplands, i.e. 1.98 ton/ha on lowlands vs. 0.98 ton/ha on uplands.

What would cause this much of difference? No doubt, water conditions contribute greatly, more abundant and stable in the lowlands as compared to droughty and less stable in the uplands. Soil is another important factor. In the low altitude, humid tropics, the temperature is high enough year round and the soil moisture condition is adequate at least for part of the year to make chemical weathering and leaching proceed quite rapidly in the upland condition. Thus, the soil materials are impoverished in a relatively short time. What is often more important is the fact that topsoils on the uplands are prone to be washed away by erosion. These soil factors should certainly be responsible for the inferior productivity of upland soils.

Therefore, in this paper first chemical and physical characteristics of upland soils will be considered in some detail and the ways to evaluate their capability will be discussed. Then, in comparison, those of lowland soils will be dealt with relying on the studies of paddy soils in tropical Asia.

Upland soils

1 General characteristics

In the Soil Taxonomy terms (USDA, 1975), what we call upland soils in this paper occur in the region with "isohyperthermic" soil temperature regime and either "udic" or "ustic" soil moisture regime. Depending on the moisture regime, as well as the nature of parent material and the age, the soil quality varies widely. Sanchez and Buol (1975) recognized two broad categories of tropical soils, high base status soils and acid infertile soils. The former includes Alfisols, Mollisols, Vertisols, Aridisols, and eutric Inceptisols and Entisols, while the latter includes Oxisols, Ultisols, Spodosols, Histosols, and dystric Inceptisols and Entisols. Since the high base status soils are not necessarily specific to the tropics and, furthermore, they have a restricted distribution, here we should better focus our attention onto the acid infertile soils in the tropics, which re-

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present, with the exception of Histosols, the products of a long-term pedogenesis and/or weathering under the humid tropical conditions.

The principal characteristics of these acid infertile soils in the tropics are summarized in the definition of an oxic horizon, which reads as follows (USDA, 1975):

i. Oxic horizon has an apparent cation exchange capacity (CEC) of the fine-earth fraction of 16 meq or less per 100g clay by NH_4OAc.

ii. It does not have more than traces of primary aluminosilicates such as feldspars, micas, glass, and ferromagnesian minerals.

The second requirement is almost self-evident. The first requirement means that clay fraction of oxic horizon materials has a low CEC; clay minerals are primarily of a mixture of 1:1 type or kaolin clay and hydrated oxides of iron and aluminum. This limit is adopted to exclude soils that have an appreciable amount of 2:1 type clay and amorphous clay that has high pH-dependent charges, such as Ando soils or Andepts containing allophane.

Recently, the term "low activity clay" is frequently used to depict such a type of clay as occurring in an oxic horizon. Clay activity is defined as the ratio of plasticity index to clay content (Skempton, 1953). More practically low activity clay may be defined, according to Uehara (1979), as that having low specific surface or low surface charge, or both.

The characteristics described above are not necessarily unique for Oxisols. Many Ultisols and even some Alfisols in the tropics share the low activity clay characteristics with Oxisols and this is the *raison d'être* of ICOMLAC which reconsiders the classification of Ultisols and Alfisols with low activity clays in the framework of Soil Taxonomy.

2 Charge characteristics

What is the specific behavior of low activity clays, or a mixture of 1:1 type clays and hydrated oxides of iron and aluminum, as contrasted to the behavior of high activity clay that occurs more frequently in the temperate zone soils?

The main source of difference is found in the origin of negative charges, which are the cause of retention capacity of cationic nutrients of the soil. The negative charge of 2:1 type clays or high activity clays originates mainly in isomorphous substitution of ions within the crystal lattice of clay minerals. Therefore, the negative charge lodges permanently on the clay surface, regardless of changes in pH and salt concentration of the medium. For this reason, 2:1 type clays are called constant surface charge minerals. On the contrary, in case of low activity clays consisting of 1:1 type clays and iron and aluminum oxides, surface charge varies with such properties as pH, concentration and ionic valence of electrolytes in the medium. Formerly, this type of charge was usually called pH-dependent charge, but as it varies with other conditions as well, presently the term "variable charge" is preferred. Further, variable charge clays may be called constant surface potential minerals in the colloid and interface chemistry terms, because for these minerals H^+ or OH^- is the potential determining ion and, thus, at a fixed medium pH surface potential assumes a constant value.

In characterizing soils with variable charge clays, the Gouy-Chapman equation is helpful (cf., Uehara and Gillman, 1980):

$$\sigma_o = \left(\frac{2n\epsilon kT}{\pi}\right)^{1/2} sinh \left(\frac{Ze}{2kT}\right) \psi_o \qquad (1)$$

where σ_o is the surface charge density, n is the electrolyte concentration of the equilibrium solution, Z is the valence of the counter ion, ϵ is the dielectric constant of the medium, k is the Boltzman constant, T is the absolute temperature, e is the charge of an electron, and ψ_o is the surface potential. Further, the surface potential of these variable charge minerals is related to H^+ ion concentration by the following Nernst type equation:

$$\psi_o = \frac{kT}{e}\ ln\ \frac{H^+}{H_o^+} = \frac{2.3kT}{e}\ log\ \frac{H^+}{H_o^+} \qquad (2)$$

where H_o^+ is the hydrogen ion concentration at which $\psi_o = 0$.

Equation (1) and (2) are combined to give

$$\sigma_o = \left(\frac{2n\epsilon kT}{\pi}\right)^{\frac{1}{2}} \left\{sinh\ 1.15Z(\mathrm{pH_o} - \mathrm{pH})\right\} \qquad (3)$$

Equation (3) indicates that at pH = pHo, surface charge density becomes zero, and as pH deviates from pHo positive or negative charge develops on the mineral surface. For this reason pHo is called zero point of charge or ZPC. This relationship between pH and σ_o may be illustrated as in Fig. 1. When pH > pHo, negative charges develop on the mineral surface, whereas when pH < pHo positive charges develop. The magnitude of the surface charge density is governed by pH, n, and/or Z, when ϵ and T remain constant.

As CEC or AEC (anion exchange capacity) is the product of surface charge density and specific surface area, the charge characteristics of clay as shown in Fig. 1 have direct practical bearing in determining the cation or anion retention property of a soil.

Another important theoretical conclusion that may be drawn from Equation (3) is that when medium pH = pHo or at ZPC, variable charge clay has zero net charge, that means clay has the least reactivity or the maximum physical as well as chemical stability. If we understand that weathering is the process in which soil materials attain the maximum stability under a given environmental condition, we can expect that at the ultimate stage of weathering, soil materials would possess a pHo which coincides with or is, at least, very close to the medium pH. This is what Mattson (1932) advocated about 50 years ago in his theory of "isoelectric weathering".

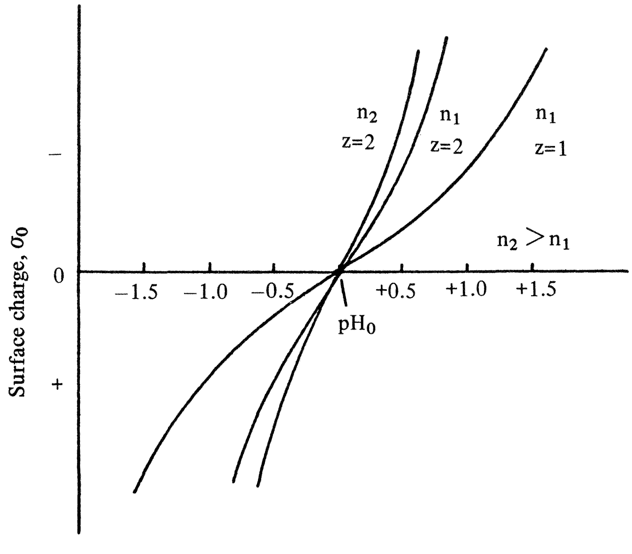

Fig. 1 Variation of charge on variable charge surface with electrolyte concentration in reference to pHo.

Let us examine some of the examples of pH-charge relationship for actual soils. Fig. 2 was cited from Sanchez (1976), in which pH-charge curves for A and B horizons of 4 soils with a high content of either allophane or oxides are shown. As seen in Fig. 1, the inflection point of those curves corresponds to ZPC of variable charge components. Therefore, the reading of the inflection point on the pH axis is pHo. Since actual soils usually have some permanent charge components, the inflection points do not normally coincide with the point of zero net negative charge and the reading of the inflection point on the charge-axis indicates the permanent charge possessed by the soil. The actual field pH of each soil is shown in Fig. 2 with the mark "I". From the curves in Fig. 2 we may be able to make the following remarks:

i. All the soils exhibit marked degrees of variable charge and small permanent negative charge, < 10 meq/100g, except B horizon of an Orthox, which has a small net positive charge.

ii. Except for one Udalf, the field soil pH coincides with or is very close to pHo, thus the contribution of variable charge components to the net charge is small. This is what Mattson's "isoelectric weathering" theory predicts.

iii. A horizon soil has always a lower pHo value as compared to B horizon soil. This is because of the presence of organic matter in A horizon which gives a lower pHo to the soil as a result of adsorption on oxide surface.

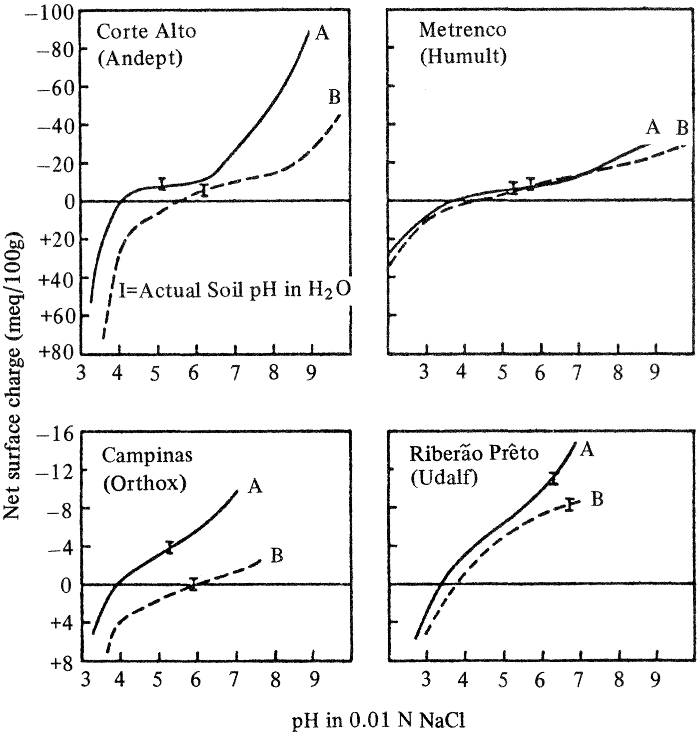

Fig. 2 **Changes in net surface charge with pH in A and B horizons of four soils high in allophane or oxides.**
(Cited from Sanchez, 1976, by courtesy of John Wiley and Sons, Inc.).

3 Fertility characteristics

We will now discuss the implications of these charge characteristics on fertility of tropical upland soils.

1) Acidity and Al-toxicity

Uehara (1979) defined ΔpH as the difference between pH in 1NCl and pH in water, ΔpH = pH_{KCl} - pH_{H_2O}. A soil that has been weathered and leached intensively under humid tropical conditions has invariably an acid reaction as long as it is negatively charged. When such a soil is put into an electrolyte solution, electric double layer is compressed and surface charge is increased by deprotonation of the surface and pH of the soil solution is lowered. Thus, ΔpH is negative. Conversely, when a soil is positively charged, protonation of the surface induced by anion sorption raises pH measured in KCl relative to pH in water. At ZPC pH_{KCl} is equal to pH_{H_2O} and ΔpH is zero. Furthermore, the magnitude of ΔpH indicates the magnitude of surface charge density. Thus, ΔpH serves as a simple yet good measure to judge the charge characteristics of a soil.

As stated before, soils with low activity, dominantly variable charge clays have usually a low negative charge, because soil pH is close to pHo, and therefore they have a small negative ΔpH. These soils usually contain a small amount of exchangeable Al and are relatively easily amended for acidity by liming to, say, pH 5.5 whereby exchangeable Al is practically eliminated. There could be acid soils with a high permanent negative charge even in the tropics, such as acid sulfate soils. In such a soil ΔpH assumes a large negative value and exchangeable Al content is so high that Al toxicity may become a problem to crops. Sanchez (1976) says, however, that Al toxicity problem is not only a matter of an absolute amount of exchangeable Al but a matter of Al saturation percentage in effective CEC. This is a subject further to be studied.

In these low pH and low negative charge soils, paucity of nutrient bases may be limiting crop growth. A small amount of application of dolomitic lime is desirable also for this reason.

2) Cation retention

From the discussions on the charge characteristics of variable charge clay it is clear that cation retention capacity or effective CEC can be increased by raising the medium pH. This can be attained, to some extent, by means of liming. However, it is also clear that by adding lime deprotonation of the surface hydroxyls of oxides is enhanced, so that the medium pH is difficult to be raised beyond a certain limit, say, pH 6. In other words, the buffering capacity of variable charge clays is very high and simple liming does not work effectively in raising the medium pH.

Another way to increase cation retention capacity is to lower pHo. This can be achieved by adding anions that can be sorbed strongly by the oxide surface, such as organic matter, phosphates and silicates. In Fig. 2 we have seen that A horizon with organic matter has always a lower pHo as compared to B horizon sample with similar mineral composition. Phosphate is known to be strongly adsorbed onto iron and aluminum oxide surface to create an additional negative charge. For example, Wann and Uehara (1978) demonstrated that addition of increasing amounts of phosphate to an Oxisol linearly lowered pHo of the soil, resulting in an increase in surface negative charge (Fig. 3).

Application of silicates is not as common as that of phosphates. Only in some countries basic slags that contain Ca-metasilicate and Ca-orthosilicate are widely applied to rice as the source of soluble silica. The effect of silicates on lowering of pHo has also been established (Furukawa *et al.*, 1981) although it is much less than that of phosphates.

3) Phosphorus sorption

Phosphorus deficiency is perhaps the most widely noted agronomic problem in the tropics. The above mentioned means that to lower pHo by an application of phosphates is justified because of the high affinity existing between phosphate and oxide surface. This very fact means that phosphates are strongly sorbed by iron and aluminum oxides to such an extent that they become almost unavailable to crops. Therefore, phosphorus deficiency problem is intrinsic to tropical soils with variable charge minerals and no easy solution is available.

There are, however, ways and means to improve the situation. Liming is one means to reduce

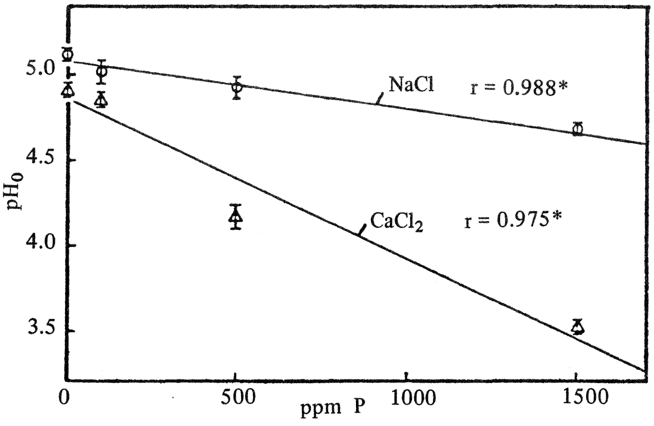

Fig. 3 Relationships between zero points of charge and P levels. (Cited from Wann and Uehara, 1978).

phosphate sorption. This is achieved through an increase in negative charge and/or decrease in positive charge on oxide surfaces. Increased negative charges would exert repulsive force on phosphates and increased medium OH^- would compete for the P-sorption sites. Moreover, as stated earlier, since these variable charge clays, though acid, do not normally contain a high amount of exchangeable Al, release and precipitation of exchangeable Al by liming would not contribute much to an additional phosphate sorption. But this would not apply to soils with a high amount of exchangeable Al. In fact, Amarasiri and Olsen (1973) reported an increase of P-sorption capacity of an Oxisol by liming.

Smyth and Sanchez (1980) recently reported that an application of $CaCO_3$ to a Haplustox at a rate to make Ca equivalent to exchangeable Al decreased the amount of P sorbed to provide 0.1 ppm P in solution by 18%. A similar treatment with $CaSiO_3$ was more effective in decreasing P-sorption; the enhanced effect may be explained by assuming competition of silicate for the P-sorption sites. Similar effect of $CaSiO_3$ in decreasing P-sorption was reported by Silva (1971) and Roy *et al.* (1971).

There could be ways to raise efficiency of fertilizer phosphates either through modification of P-fertilizer forms or through fertilizer placement techniques. For example, large pelleted fertilizer placed near the crop rooting zone may be one way to achieve a higher fertilizer efficiency.

4 Physical characteristics

As shown in Fig. 2, tropical soils dominated by low activity clays have a medium pH close to pHo. This means that clay reactivity is low and, because of very low surface charges, clay particles tend to coagulate to form aggregates, which are further stabilized by coating and cementation by iron and aluminum oxides. Therefore, with respect to structural stability tropical soils with low activity clays are generally better than those with high activity clays.

However, such an aggregate status does not necessarily guarantee a better moisture retention property. Sharma and Uehara (1968) noted that a heavy textured soil dominated by kaolin and oxides behaved like a sandy soil in moisture retention-release process. Most of the readily mobile water held at saturation was lost at low tensions below 0.2 bars, while the rest of the water was removed only at very high tensions $>$ 100 bars. Therefore, the available water-holding capacity is very low. Moormann and Van Wambeke (1978) compared low activity clays with high activity clays with respect to CEC and available water-holding capacity and obtained 14.6 ± 3.6 meq/100g and

16.5 ± 6%, respectively, for the former as against 62.8 ± 13.5 meq/100g and 38.7 ± 19.4%, respectively, for the latter.

Normally fine textured soils with stable aggregates have a high infiltration rate and an adequate permeability which protects the soils from erosion. However, there are soils with low activity clays, particularly Ultisols and Alfisols, which have coarser textured surface soil. They tend to form surface crust, thus reducing entry of water into the soil and increasing runoff and erosion hazards (Moormann and Van Wambeke, 1978). An effective countermeasure may be mulching and keeping plant canopy, not to expose the soil surface to the impact of rain drops and direct insolation.

In relation to those latter soils, compaction is another problem. After deforestation and start of cultivation, surface soil temperature goes up and this would accelerate decomposition of organic matter, which leads to breakdown of aggregates and, accordingly, to soil compaction. One experiment carried out by Kyuma *et al.* in Thailand (unpublished) revealed that soil temperature at the depth of 30 cm was kept higher by 2 to 3 degrees for most part of a year and this led to 50% more soil respiration in a cultivated plot as compared to a plot under forest canopy.

5 Capability evaluation of upland soils

We have so far discussed the characteristics of tropical upland soils with low activity or variable charge clays. A representative member of this group of soils is acid, poor in cationic nutrients and nutrient-holding capacity, also poor in available water-holding capacity, and high in P-sorption capacity. It may also be prone to suffer from micronutrient deficiency, e.g., Mo, Zn and Cu. But at the same time it has stable aggregates and good permeability and is not subject to severe compaction and erosion.

There are, however, varieties of tropical soils in which variable charge clays are not dominant or even permanent charge, high activity clays make up the mineral colloidal fraction. Naturally, the behavior of these soils is different and the methods of soil management should be geared accordingly. Therefore, what is important is to know the characters of the soils concerned.

The following measurements, in addition to the routinely analysed items, would help identify the soil characters:

i. $\Delta pH = pH_{KCl} - pH_{H_2O}$

ii. pHo A usually used method is rather involved. Keng (1974) statistically established the following relationship.
$pHo = pH_{KCl} + \Delta pH$

iii. Effective CEC (CECe) = sum of exchangeable bases + KCl extractable Al+H

iv. Al-saturation = (exchangeable Al/CECe) x 100

v. P-sorption capacity A method proposed by Fox and Kamprath (1970) estimates the amount of P to be applied to provide 0.2 (or 0.1) ppm of P in solution. In Japan the following method has been widely used: 100 ml of 2.5% $(NH_4)_2HPO_4$ solution is added to 50g soil and P in the supernatant is measured after 24 hours. The result is expressed in P_2O_5 sorbed in mg/100g soil. Normally, Ando soils (Andepts) give values $>$ 2000, while ordinary mineral soils give values below 1000.

As a more systematic method of soil capability evaluation, Buol *et al.* (1975) proposed a system named "Soil Fertility Capability Classification" for the use particularly in tropical America. It consists of 3 levels: Soil type (based on surface soil texture), Substrata type (subsoil texture), and Condition modifiers (specific properties, such as acidity, Al-toxicity, low CEC, etc., are noted using specific symbols). The way of interpretation for each of the classes is established.

Kyuma *et al.* (1977) proposed a numerical method to evaluate upland soil capability for Japanese soils. Both field and laboratory data were used for a numerical evaluation of available water-holding capacity, soil tilth, and fertility. The same approach should be applicable to the tropical conditions.

Lowland soils

1 General characteristics

For the present discussion, it may be most convenient to use the definition of "aquic" moisture regime of Soil Taxonomy (USDA, 1975) to define lowlands. It reads: "The aquic moisture regime implies a reducing regime that is virtually free of dissolved oxygen because the soil is saturated by ground water or by water of the capillary fringe . . . The duration of the period that the soil must be saturated to have an aquic regime . . . must be at least a few days." If we define a lowland as the land having aquic moisture regime at least for a few days in the year, most of the lands called by such conventional terms as alluvial plains, deltaic plains, coastal plains, flood plains, etc., are covered.

Soils on the lowlands are almost exclusively on sediments of relatively recent geological origin. The greater part of lowland soils is on the Holocene alluvial and deltaic sediments and some are on the late Pleistocene alluvia constituting fan and terrace surfaces. This fact implies first of all that lowland soils are undeveloped in terms of their profile morphology, and secondly that they are relatively enriched with mineral nutrients as compared to those in the areas of origin of the parent sediments.

Soils occurring in lowlands in the Soil Taxonomy terms are mostly aquic suborders of Entisols and Inceptisols., i.e. Aquents and Aquepts. Other soils of some importance that occur in lowlands include Aqualfs and Aquults on terrace surfaces. Although aquic feature is not clearly visible, Vertisols also occur in lowlands. They are, however, confined to fine clayey, montmorillonite rich sediments under the climate with distinct dry seasons.

2 Material characteristics

The fact that the soils in the lowlands have undergone little or no pedogenetic modification implies that the soil characteristics are determined directly by the nature of the parent sediments. It follows further that variability of lowland soils is wide, because the nature of the parent materials is conditioned by the geology and the degree of weathering in the catchment area and/or the milieu of sedimentation. At one extreme, fresh volcanic ejecta are laid down in the lowlands, while at the other extreme there are soil materials indistinguishable from those in an oxic horizon. It should be noted that the range of variability is wider in the tropics than in the temperate and cold regions.

Kawaguchi and Kyuma (1977) attempted a classification of soil materials for 410 paddy soil samples taken from tropical Asian countries and set up 10 soil material classes on the basis of their textural composition and total chemical composition. The relevant data for these 10 material classes are given in Table 1. As seen from the data of clay mineralogy and CEC (measured with a method comparable to pH 7 NH_4 OAc method), none of the soil materials appears to contain low activity clays in a considerable amount. Only the class XIII materials, mainly derived from Mesozoic sandstones in Northeast Thailand and Cambodia, contain clays resembling low activity clays in uplands. Thus, the greater part of lowland soils can be treated as dominated by permanent charge or high activity clays.

Such a contrast in charge characteristics between upland soils and lowland soils can be seen if we take soil samples along a transect from upland to lowland in an area made up of the same kind of parent rock. One typical example is given in Table 2, which shows the results of clay mineral analysis carried out on the samples taken from Saraburi-Lop Buri area of Central Thailand (Kawaguchi and Kyuma, 1969). Two end-members of the sequence belong to Pak Chong series (Oxic Paleustult) and Lop Buri series (Typic Pellusterts), respectively. As shown in Table 2, one is strongly red colored, suggesting a high iron oxide content, and contains exclusively kaolinite, while the other is black in color and almost purely montmorillonitic in clay mineralogy.

Table 1 Mean mechanical and total chemical composition and some other related properties of lowland soil samples falling in each soil material class

Class (No. of Samples)		I (61)	II (68)	III (66)	IV (29)	V (42)	VI (31)	VII (25)	VIII (44)	IX (25)	X* (19)	Whole (410)
Sand	%	12.40	34.43	8.64	21.83	58.72	20.33	18.82	73.78	68.38	54.63	33.81
Silt	%	22.73	34.05	35.21	33.93	19.84	25.92	49.76	15.54	10.05	25.70	27.60
Clay	%	64.87	31.52	56.15	44.20	21.43	53.76	31.43	10.68	21.56	19.68	38.59
SiO_2	%	62.85	80.45	67.40	66.55	73.81	59.00	66.65	94.62	77.55	62.70	72.12
Fe_2O_3	%	9.90	3.07	5.71	7.69	4.51	11.95	6.71	0.82	5.41	6.89	5.96
Al_2O_3	%	22.12	12.78	21.53	19.25	14.58	20.98	18.31	3.45	11.87	18.41	16.38
CaO	%	1.31	0.39	0.46	1.95	2.03	3.22	1.58	0.22	0.98	6.89	1.42
MgO	%	0.90	0.38	0.94	1.23	0.95	1.57	1.98	0.05	0.68	2.28	0.92
MnO_2	%	0.22	0.06	0.06	0.18	0.11	0.31	0.10	0.02	0.14	0.16	0.12
TiO_2	%	1.54	0.99	1.11	1.04	0.86	1.59	0.96	0.64	1.98	0.94	1.14
K_2O	%	1.04	1.85	2.67	1.96	2.99	1.16	3.59	0.40	1.31	1.49	1.83
P_2O_3	%	0.12	0.09	0.13	0.15	0.15	0.22	0.13	0.06	0.12	0.24	0.13
pH		6.1	5.3	5.2	6.5	6.8	7.0	6.6	5.3	6.0	6.9	6.0
PBS	%	94.2	59.1	81.5	100.0	103.2	106.2	98.9	65.0	83.0	105.8	85.6
CEC	meq/100g	31.1	12.3	20.4	26.7	13.9	34.4	15.4	4.2	10.3	15.5	18.6
7A	%	43.1	52.4	46.7	32.6	36.8	37.3	32.4	70.1	63.0	29.3*	46.4*
10A	%	5.0	19.2	20.9	12.4	20.2	3.9	28.2	5.1	8.2	12.3*	13.9*
14A	%	51.9	28.5	32.4	55.0	43.0	58.9	39.4	24.8	28.8	58.4*	39.7*

* Because four samples in group X have no crystalline minerals, the means for the other samples were taken.

Table 2 Description and approximate clay mineral composition of surface soils of a topo-sequence derived from marl

Soil	Sampling Site	Land Use	Soil Colour	7 Å	10 Å	14 Å	Pisolith
LB-1	Foot slope of a marl hill	Upland	2.5YR4/6	100%	0%	0%	++
LB-2	0.3 km N of LB-1, sloping	Upland	7.5YR4/4	80	0	20	+
LB-3	4 km N of LB-2, level	Paddy	10YR3/1	10	0	90	+
LB-4	6 km N of LB-3, level	Paddy	N2/	5	0	95	–

3 Fertility characteristics

Lowland soils have important fertility features which are associated with aquic moisture regime. First of all, they receive substances lost in erosional and leaching processes in the catchment uplands, thus, they are advantageous in maintaining soil fertility. Instead of depletion by erosion, enrichment by silting may be counted positively in the long-term rejuvenation of soil materials. Dissolved nutrients, such as Ca, Mg, K and Si, in the flood or irrigation water are readily available to the crops growing on lowlands.

Secondly, phosphorus and nitrogen status is also favorable in lowland soils. Nitrogen fixation by lower plants and microbes is said to be much higher under waterlogged conditions as compared to upland conditions, except for uplands carrying leguminous crops. Leaching loss of nitrogen applied or released by mineralization of soil organic matter is lesser than in uplands because the ammoniacal nitrogen can stay adsorbed on the exchange complex. However, losses due to denitrification in the lowland soils are considerably higher than in upland soils.

Concerning phosphorus, its availability is rendered more favorable in lowland soils with aquic moisture regime than in upland soils. This is because of such causes as release of occluded phosphorus in the course of iron reduction, higher solubility of phosphorus from iron and aluminum phosphates under reduced, raised pH condition, and so forth. In short, phosphate availability is kept higher in lowlands as compared to uplands for the same total content of phosphorus.

What has been stated above concerning the advantage in soil fertility aspects of aquic lowland soils in comparison with upland soils may be summarized as follows:
i. Ease of soil conservation, and
ii. Ease of maintenance of soil fertility.
These two are even more important in the tropics than elsewhere.

4 Physical characteristics

Since the greater part of lowland soils is derived from fine clayey sediments in the alluvial and deltaic plains, physical properties of soils are generally poor. Under the monsoonal climatic conditions, soils in the lowlands are too wet during the rainy season and too dry during the dry season. During the wet season workability of soils is poor, while during the dry season soils tend to cohere to form very hard, big blocks and again they are difficult to work with. Thus, physical properties of clayey lowland soils often pose severe constraints to upland crop cultivation in rice-based multiple cropping system. Lighter textured soils are preferentially used in such cropping systems.

For rice cultivation, however, soil physical properties are relatively unimportant as long as sufficient water is available. It seems probable that a yield level up to 4 to 5 ton of paddy per hectare would not pose any particular requirements to physical properties of rice growing soils. This is another reason, besides those stated in relation to soil fertility, why rice is preferred to upland crops on the lowlands.

5 Fertility evaluation

Relying on laboratory data and using multivariate statistical methods Kawaguchi and Kyuma (1977) demonstrated in their study on paddy soils in tropical Asia that soil fertility is made up at least of three independent components and evaluated numerically these three fertility components for each sample soil. The ratings for several selected geographic regions in South and Southeast Asia are given in Table 3. The three fertility components have the following characteristics.

(1) Inherent potentiality (IP) – the soil character determined by the nature and amount of clay and base status,
(2) Organic matter and nitrogen status (OM) – the soil character related to the organic matter and nitrogen reserve.
(3) Available phosphorus status (AP) – the soil character related to available phosphorus supplying power.

As the numerical rating was done to make the overall mean for the 410 samples zero and variance one, the positive figures mean above-average rating and the negative figures below average.

It is generalized from the above results that IP is highly rated in the regions where active volcanism can continuously rejuvenate the soil materials. It is also high in the deltaic areas where sediments from soils with more or less ustic moisture regime are deposited. On the contrary, IP ratings are low for the soils on sandy old alluvia and on the sediments derived from acidic rocks. High OM ratings are correlated with the more humid climatic condition and fine textured sediments in the lower terrain position. But the greater part of lowland soils occurring in subhumid to semi-arid climatic regions has low OM ratings and this is the majority. AP ratings are low in the areas with acidic and/or sandy sedimentary rocks as the parent rock of the soil. High AP ratings are for the soils in Ganges as well as Brahmaputra sediment areas of Bangladesh and in Godavari-Krishna delta.

Moormann and Van Breemen (1978) assessed the quality of lowland soils as related to rice production from the following viewpoints; moisture availability, oxygen availability in the root zone, nutrient availability, toxicity of soil and water, salinity and alkalinity, flooding hazards, workability and terrain factors, and resistance to erosion. Obviously acid sulfate soils, saline and sodic (or alkali) soils, and organic soils, among others, have serious constraints in one or several of these criteria.

Table 3 **Means and standard deviations of the three factor scores for selected regions**

Regions	No. of Samples	IP		OM		AP	
		Mean	S.D.	Mean	S.D.	Mean	S.D.
South Asia							
India: Godavari-Krishna delta	10	1.38	0.29	−0.73	0.47	1.11	0.95
Bangladesh: Ganges	15	0.33	0.35	0.04	0.82	0.90	0.50
Brahmaputra	13	−0.57	0.48	−0.01	0.64	1.01	0.66
Madhupur-Barind	9	−0.75	0.60	0.35	0.64	−0.14	0.40
Marginal	16	−0.87	0.62	0.36	0.66	−0.06	0.77
Sri Lanka: Wet and Intermediate zones	14	−1.07	0.64	0.84	1.10	−0.10	0.64
Dry zone	19	−0.10	0.76	−0.36	0.70	−0.12	0.67
Southeast Asia							
Thailand: Northeast Plateau	32	−1.18	1.27	−1.14	0.77	−0.94	0.70
Upper Central Plain	14	−0.04	0.76	−0.05	0.49	−0.31	0.69
Bangkok Plain	24	0.53	0.64	0.24	0.66	−0.51	0.86
South	6	−0.40	0.74	0.58	0.48	−0.29	0.39
Cambodia: Central Plateau	8	−0.91	0.76	−0.60	0.94	−1.19	0.69
Peninsular Malaysia:							
Kedah-Perlis Plain	10	0.25	0.44	1.21	0.56	0.02	0.54
East Coast	10	−1.23	0.20	0.78	0.59	−0.54	0.57
Indonesia: Central and East Java	28	0.91	0.59	−0.29	0.53	0.10	0.81
Philippines: Central Luzon	25	0.91	0.54	−0.10	0.41	−0.36	0.97

Summary

Soil qualities of low altitude, humid to seasonally dry tropics have been reviewed based on the results of recent studies. Many of the chemical and physical properties of tropical upland soils dominated by low activity clays appear to be governed by their variable charge characteristics. Management practices of these soils should be developed and geared taking the charge characteristics into consideration.

Most of lowland soils in the tropics seem to have different characteristics from upland soils. They seem to have high activity clays and the technical knowhow developed in the temperate lowland is generally applicable to the tropical lowland soils. Acid sulfate soils, saline and sodic soils, and organic soils of Histosols in the tropics require further research before they may be turned into productive agricultural lands.

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Discussion

Watanabe, I. (IRRI): The selection of only a few days of submergence for defining an "aquic" moisture regime is not appropriate. What is your opinion on this subject?

Answer: I agree with you that such a definition which is given in the original textbook of Soil Taxonomy is perhaps too ambiguous.

Li, C.K. (China): What are the color standards you use?

Answer: We use the Munsel color notation to describe the color of a soil. Three components are identified: hue, value and chroma.

Wada, K. (Japan): With reference to the table you showed, is there any possibility that materials derived from parent rocks other than limestone might have been mixed in the paddy soils? It seems difficult to understand the marked difference in clay mineral formation between the upland and paddy soils only in terms of differences in upland and paddy environment.

Answer: I cannot give you a precise answer. The samples of upland soil were taken at the foot of a limestone hill. The samples of lowland soil were taken in an area with Lop Buri soil series which is considered to have derived from marl.

Somasiri, S. (Sri Lanka): You presented data for four soils on a toposequence where the lowland soils had high activity clays. Is it possible that under lowland conditions, 2:1 clays might have been formed during pedogenesis?

Answer: There could be two factors involved. 1) The higher pH condition resulting from the inflow of leached basic cations from the surrounding uplands might have been conducive to the formation of 2:1 clays. 2) The inflow of 2:1 type clays to lowland areas, which are finer in size and undergo ready dispersion might have operated as a sorting mechanism in the deposition process.