Major Soils of Southeast Asia and the Classification of Soils Under Rice Cultivation (Paddy Soils)

by

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1. Introduction

A predominantly accepted concept of a soil is that it is formed as an integrated result of the effects of climate and organisms acting upon parent materials as conditioned by relief over time. In evaluating the agricultural potentials of land, one cannot overlook the most fundamental of methods which is soil surveys. For this reason, efforts along this line have been very notable in recent years in the developing countries of Southeast Asia.

In this paper, the authors will first attempt to correlate various soil units, at the great soil group level, which appear in legends of soil maps of these countries, then discuss the problem of the classification of paddy soils in view of the fact that there are many different ideas on their taxonomic positions. A tentative proposal is then made to help clarify and to make easier the present ambiguous use of the term *paddy soil*.

The countries in Southeast Asia included in this paper are Burma, Cambodia, Ceylon, Indonesia, Malaysia (Malaya), the Philippines, Thailand and North and South Vietnam. Laos was not included because of a lack of materials.

2. Legends of the Soil Maps of the Southeast Asian Countries

There are several people who can not be forgotten in relation to soil surveys in Southeast Asia ; among them, Pendleton in Thailand, Owen in Malaya, Joachim in Ceylon, Dutch workers in Indonesia, and French workers in Indochina. However, the methods of soil surveys and the idea of soil classification are always in flux, and are constantly being revised. Here the authors refer only to the most recent soil maps available to them.

The legends will be given in full because they may help the readers understand the relationships of soils to their parent materials and to topographic elements. Presentation will be made alphabetically according to the names of the countries.

Burma

During 1957-1959, soil surveys were carried out by the Land Use Bureau with technical assistance by four Russian specialists in order to prepare a soil map on a scale of 1 : 253,000. The map and its explanatory report are not available to the authors, although a paper by Karmanov[13] has recently appeared in *Pochvovedenie*, in which a soil map reduced to the scale of approximately 1 : 10,000,000 is reproduced. The legends for this map are as follows :

1. Light-colored meadow soils (mainly gley soils)
2. Light-colored meadow soils in association with meadow-bog soils and meadow-alluvial soils
3. Light-colored meadow soils (or meadow-bog soils), saline
4. Dark-colored meadow soils
5. Dark compact soils of dry savanna
6. Reddish-yellow soils of tropical monsoon forests
7. Reddish-cinnamon soils of dry tropical forests and bushes
8. Red-brown soils of dry savanna
9. Weakly developed gravelly red-brown soils of dry savanna
10. Mountain red-yellow soils
11. Red soils of mountain tropical forests
12. Soils of high mountainous area (little studied)
13. Soils of mangrove forests

Cambodia

An exploratory survey of Cambodia was carried out in 1961-1962 by C. D. Crocker[2] of USAID and a general soil map of a scale 1 : 1,000,000 was published in 1963. Soil units for the map legend, according to Crocker, are at the categorical level of great soil groups and sub-groups, as follows :

1. Red-yellow podzols
2. Latosols
3. Planosols
4. Plinthite podzols
5. Cultural hydromorphics
6. Grey hydromorphics
7. Plinthitic hydromorphics
8. Brown hydromorphics
9. Alumisols
10. Regurs

11. Acid lithosols
12. Basic lithosols
13. Alluvials
14. Brown alluvial soils
15. Lacustrine alluvials
16. Coastal complex

Ceylon

Panabokke compiled a soil map of Ceylon in 1962 on a scale of 8 miles to the inch (1 : 506,880). Soil units in the legends are the great soil groups classified by Moormann and Panabokke[18] in 1961. Detailed reconnaissance surveys are in progress in the areas of a large scale multi-purpose development project. A new soil map will be compiled before long based on the new survey data. Here legends of the 1962 Panabokke map are given:

1. Reddish-brown earths
2. Non-calcic brown soils
3. Reddish-brown lateritic soils
4. Red-yellow latosols
5. Red-yellow latosols (calcic sub-group)
6. Red-yellow podzolic soils (modal)
7. Red-yellow podzolic soils (sub-group with plinthite)
8. Red-yellow podzolic soils (sub-group with prominent A_1 horizon)
9. Immature brown loams (dry zone sub-group)
10. Immature brown loams (wet zone sub-group)
11. Regosolic alluvial soils
12. Regosols and alluvial soils
13. Solodized solonetz and solonchak
14. Rendzina soils
15. Grumusols

Indonesia

The Soil Research Institute of Indonesia initiated an extensive soil survey project in 1955 in connection with a five-year development plan for the country. Dudal of FAO joined with and assisted the staffs of the institute. Thirty-two legends were established in 1960 for the exploratory soil map of the whole of Indonesia[15], of which twenty-four appear in the map for Java and Madura (scale 1 : 1,000,000), which is available to the authors. Here all 32 map legends are given (the numbers for those not appearing in the Java and Madura map are put in brackets).

1. Organosol and alluvial from marine, river, lake deposits on level plain or bottom land

2. Alluvial from river and lake deposits on level plain or bottom land
3. Regosol and lithosol from sedimentary and igneous rocks on undulating to hilly land
4. Regosol from calcareous sedimentary rocks on hilly land
5. Regosol from dunes and coastal bars on rolling land
6. Regosol from basic and intermediate igneous rocks on hilly to mountainous land
7. Regosol from acid igneous rocks on hilly land
8. Regosol and latosol from basic and intermediate igneous rocks on hilly to mountainous land
9. Lithosol and regosol from igneous rocks on mountainous land
10. Grumusol from sub-recent clay deposits on level plain
11. Grumusol from sedimentary and igneous rocks on rolling land
12. Latosol and andosol from basic and intermediate igneous rocks on hilly to mountainous land

〔13〕 Latosol and andosol from acid igneous rocks on hilly to mountainous land

14. Latosol from basic and intermediate igneous rocks on rolling to mountainous land
15. Latosol from acid igneous rocks on rolling to mountainous land

〔16〕 Latosol from sedimentary and igneous rocks on rolling to hilly land

〔17〕 Lateritic from igneous and sedimentary rocks on undulating to rolling land

18. Red-yellow podzolic from sandstones and acid igneous rocks on hilly to mountainous land
19. Red-yellow podzolic from acid sedimentary rocks on rolling land
20. Complex of red-yellow podzolic, latosol and lithosol from sedimentary and igneous rocks on hilly to mountainous land
21. Red-yellow mediterranean and grumusol from calcareous sedimentary rocks on hilly to mountainous land
22. Red-yellow mediterranean and grumusol from basic and intermediate igneous rocks on hilly land
23. Complex of red-yellow mediterranean, grumusol and regosol from sedimentary rocks on hilly to mountainous land

〔24〕 Andosol from basic and intermediate igneous rocks on undulating to rolling land

25. Andosol from basic and intermediate igneous rocks on mountainous land

〔26〕 Andosol from acid igneous rocks on mountainous land

27. Andosol and regosol from basic and intermediate igneous rocks on mountainous land

〔28〕 Andosol and regosol from acid igneous rocks on mountainous land

29. Grey hydromorphic and planosol from sub-recent clay deposits on level plain
〔30〕 Podzol from dunes and coastal bars on undulating land
〔31〕 Complex of red-yellow podzolic, lithosol and regosol from sedimentary and metamorphic rocks on mountainous land
32. Complex of red-yellow mediterranean and lithosol from sedimentary and metamorphic rocks on mountainous land

Malaya

Panton's 1962 soil map of Malaya[21] is of quite provisional nature, compiled from relatively little survey data on a scale of 24 miles to the inch (1 : 1,520,640). Schematic reconnaissance surveys are now going on for potential agricultural lands and soil maps are being prepared on a larger scale with series and associations as the basic map units. Legends of the 1962 map are as follows:

1. Lithosols and shallow latosols on steep mountainous and hilly land
2. Red and yellow latosols and red and yellow podzolic soils derived from acid igneous rocks
3. Red and yellow latosols and red and yellow podzolic soils derived from various sedimentary rocks
4. Red and yellow latosols and red and yellow podzolic soils derived from older and sub-recent alluvium
5. Reddish-brown latosols derived from basic and intermediate igneous rocks
6. Laterite soils
7. Low humic gley soils
8. Azonal estuarine and coastal soils
9. Podzols
10. Organic soils
11. Disturbed land

The Philippines

Since 1934 reconnaissance surveys had been made by the Bureau of Soils and 46 out of 53 provinces of the Philippines were surveyed by 1964.[1] Soil maps on a scale 1 : 75,000 - 1 : 250,000 with series or type as the basic mapping unit were published by provinces. However, classification at great soil group level for the Philippines has not as yet been published.

Thailand

Since 1962 the Soil Survey Division of Department of Land Development, joined by Moormann of FAO, has been carrying out detailed reconnaissance surveys in many project areas and has been continuously publishing soil maps on a scale of 1 : 50,000 with series and associations as the basic map units. However, classification at great soil group level for all Thai soils has not been worked out yet. Santhad Rojanasoonthon[26] conducted great soil group surveys in several scattered areas and the results were compiled in soil maps of 1 : 250,000. The soil units of the legends of these maps are given below* :

1. Lithosols
2. Regosols
3. Alluvial soils
4. Low humic gley soils
5. Grumusols
6. Rendzina soils
7. Grey podzolic soils
8. Red-yellow podzolic soils
9. Reddish-brown lateritic soils
10. Yellow latosols
11. Red latosols
12. Dark reddish-brown latosols
13. Red-brown earths
14. Non-calcic brown soils
15. Solodized solonetz

Vietnam (North)

Staffs of the Crop Science Research Institute of the Democratic Republic of Vietnam, joined by Fridland of the Dokuchaev Soil Institute, made soil surveys in 1957-1958 and prepared a schematic soil map and its explanatory report in 1958-1959, neither of which are available to the authors. Here legends of the soil map reproduced in Fridland's book *Nature of North Vietnam*[8] on a scale of approximately 1 : 3,000,000 are given :

I. Soils of the plain territory
  A. Alluvial flood plain soils, receiving fresh deposits annually
    1. Neutral and slightly alkaline, on the river Hong-Ha deposits
    2. Neutral and slightly acid, influenced by calcareous water
    3. Acid, on deposits of various rivers
  B. Alluvial deltaic soils, not receiving fresh deposits regularly (mostly paddy soils)
    4. Neutral and slightly acid, on the river Hong-Ha deposits
    5. Neutral and slightly acid, mostly found under the influence of calcareous water

* Numbers for the soil units are given by the authors.

6. Acid, on deposits of various rivers

C. Bog soils and saline soils

7. Gley-bog
8. Silty-bog
9. Alluvial saline (Solonchak-like)
10. Coastal solonchak (soils of mangrove forests)
11. Acid saline (aluminous)

II. Soils of hilly territory

Lateritic soils of permanently humid tropical forests

12. Red structured, developed on basic and intermediate igneous rocks
13. Brownish-yellow structureless, often having indurated laterite horizon, developed mostly on older alluvial and diluvial deposits
14. Red and yellow lateritic soils of hilly land in association with lateritic soils of the basin altered by rice cultivation
15. Lateritic soils altered by rice cultivation, often degraded, with scattered patches of red and yellow lateritic soils of hills

III. Soils of mountainous areas

16. Mountain lateritic-humic
17. Mountain humic-lateritic
18. Mountain lateritic
19. Lateritic soils on weathered products of limestone (terra rossa and others) in association with limestone outcrops
20. Rocky limestone hill with scattered patches of lateritic soils on weathered products of limestone
21. Strongly eroded lateritic soils and various mountain soils
22. Coastal sands of plains and dunes

Vietnam (South)

Moormann of FAO made a reconnaissance survey in 1957-1960, and in 1961 a general soil map of a scale of 1 : 1,000,000 and an explanatory report attached to it were published.[17] Soil units in the legends are mostly great soil groups, but some of them are on the lower categorical levels, as follows:

1. Undifferentiated alluvial soils
2. Saline alluvial soils
3. Acid alluvial soils (acid sulphate soils)
4. Very acid alluvial soils (strongly acid sulphate soils)
5. Brown alluvial soils of the river levees
6. Regosols on white and yellow sand dunes
7. Regosols on old red sand

8. Shallow regurs and latosols, generally shallow, on basalt ; variable topography
9. Non-calcic brown soils on acid rocks ; undulating to rolling topography
10. Non-calcic brown soils on old alluvial sediments ; plane to undulating topography
11. Sandy podzolic soils on acid rocks ; plane to rolling topography
12. Red and yellow podzolic soils on acid rocks ; plane to rolling topography
13. Red and yellow podzolic soils on old alluvial sediments ; plane to rolling topography
14. Grey podzolic soils on old alluvial sediments ; plane to undulating topography
15. Low humic gley soils on old alluvial sediments ; plane topography
16. Podzolic soils and regurs on old alluvial sediments ; plane to undulating topography
17. Complex of podzolic soils on old alluvial sediments and alluvial soils ; plane to undulating topography
18. Complex of mountainous soils, mostly red and yellow podzolic soils and lithosolic soils
19. Reddish-brown latosols on basalt ; plane to rolling topography
20. Red and yellow latosols on basalt ; undulating to rolling topography
21. Earthy red latosols on basalt ; undulating to rolling topography
22. Shallow latosols on basalt ; plane to undulating topography
23. Reddish-brown latosols and red latosols on basalt ; rolling topography
24. Reddish-brown latosols and compact brown latosols on basalt ; plane to rolling topography
25. Peat and muck soils

3. Correlation of the Soil Units at the Great Soil Group Level

Using their own experience and relevant literature as bases, Dudal and Moormann[5] gave brief descriptions for the major soil groups of Southeast Asia on their morphology, physical and chemical characteristics, environmental conditions, geographical distributions, land use, and agricultural potentials. They also reviewed various nomenclatures in use for these soil groups in the countries of Southeast Asia. Their descriptions for each great soil group and the order and suborder names (in some cases also great group names) according to the " 7 th approximation "[30] will be cited briefly. Under each great soil group name the equivalent soil units in the map legends mentioned in the preceding section will be shown. Then those many re maining soil units which will have not been correlated with the great soil groups as defined by Dudal and Moormann will be presented.

A. Great soil groups as defined by Dudal and Moomann and their equivalents

1. Alluvial soils (entisol)

For South Vietnam, Moormann set up 5 legends as subdivisions of this group, *i. e.* undifferentiated, saline, brown (river levee), acid and very acid, of which the latter two, acid and very acid alluvial soils are the so-called cat clays (katteklei) or acid sulfate soils.

2. Regosols (entisol)

Sandy regosols along the sea coast and regosols from materials of volcanic origin are the two major groups. The latter is found in Indonesia and the Philippines.

3. Grumusols (vertisol—aquert, ustert)

Oakes and Thorp[19] proposed this to include dark clay soils of the warm regions, *i. e.* black cotton soils, regurs, tirs, rendzinas. Mohr and van Baren[16] called similar soils of this group found in Indonesia "margalitic soils and black earths".

The present group as proposed by Dudal and Moormann seems to exclude rendzinas. Among the legends of Ceylon, Indonesia, and Thailand, the soil unit grumusol was used in exactly this way. Regurs in South Vietnam and Cambodia are obviously included in the present group.

4. Andosols (inceptisol—andept)

This name was first used in the reconnaissance survey of Japan in 1951.[23] The soil unit andosol appears among the legends of Indonesia, where various names such as high mountain soils, mountain black earths, humic mountain soils, and black latosols were formerly used for the same unit.

5. (Acid) Brown forest soils (inceptisol—ochrept; in part, mollisol)

This group is nearly equivalent to the soils bearing a similar nomenclature in temperate zones.

Immature brown loams of Ceylon may be included in the group.

6. Podzols (spodosol—aquod, humod, orthod)

Soils usually called ground water podzols and humus podzols may correspond to the present group.

In Indonesia and Malaya podzols are delineated on the soil map.

7. Non-calcic brown soils (alfisol—ustalf—ultustalf, typustalf)

This group appears in Ceylon, Thailand and South Vietnam. According to Dudal and Soepraptohardjo[6], a part of red yellow mediterranean soils among the soil units for Indonesia corresponds to the present group.

8. Red-brown earths (alfisol—ustalf—rhodustalf, ultustalf, typustalf)

In Thailand a soil unit has the same name. Reddish-brown earths in Ceylon, a part of red-yellow mediterranean soils, in Indonesia are the equivalents of the group. Although the present group name does not appear among the legends of Cambodia, it is known to occur also in Cambodia according to Dudal and Moormann.

9. Low humic gley soils and grey hydromorphic soils (ultisol—aquult; alfisol—aqualf)

Low humic gley soils in Malaya, Thailand and South Vietnam, grey hydromorphics in Cambodia, grey hydromorphics and planosols in Indonesia may be, at least in part, included in the present group. Dudal and Moormann define the group as hydromorphic soils with a textural B horizon but not qualified to be humic gley soils due to the lack of a thick or highly humic A horizon. Dudal and Soepraptohardjo used the name grey hydromorphics for a group including both planosols and low humic gley soils of 1949 USDA system.[27] Hydromorphic soils with soft plinthite at variable depths which are often classified as ground water laterites may be, at least in part, included in the present group.

This group does not appear among the legends of the Ceylon map, but Moormann and Panabokke separated low humic gley as an equivalent of that of South Vietnam.

10. Red-yellow podzolic soils (ultisol—ochrult)

In Ceylon, Indonesia, Malaya, Thailand and South Vietnam this group is mapped over extensive areas. The major part of red-yellow podzols of Cambodia may be equivalent to this group.

According to Dudal and Moormann there are some variants that fall in the alfisol order, ultustalf great group of the "7 th approximation", which occur in the monsoon regions.

11. Grey podzolic soils

This is a great soil group first proposed by Dudal and Moormann in the soil surveys of the lower Mekong region and must not be confused with grey wooded soils of the 1949 USDA system which is also called grey podzolic soils.

Most of the grey podzolic soils are formed on acid, light to medium-textured old alluvium (forming river terraces) in the continental part of Southeast Asia. They occur most commonly in the monsoon areas with an anual rainfall greater than 1500 mm., but can also be found in drier areas such as northeast Thailand.

Profile development is rather poor showing fairly uniform color, but upon analysis differentiation into eluvial A and illuvial textural B horizons is consistently noticed. Most profiles have concretionary or continuously layered laterite in the subsoil.

Weatherable minerals are rarely found. The degree of base saturation ranges from 10 to 65% and pH of the surface horizon is around 4.5. Cation exchange capacity is low, often below 10 m.e./100 g. The clay minerals are almost entirely kaolin minerals.

Soils once called "terres grises" by French workers and in Thailand the Khorat series and ground water laterite by Pendleton may correspond to the present group.

No satisfactory place for this group is yet available in the "7 th approximation", but most of the soils except those of high base saturation would be classified as ochrults.

In Thailand and South Vietnam the present group appears in the map legends.

12. Dark red and reddish-brown latosols (oxisol—udox, ustox)

Soils of this group develop mostly on basic parent materials such as basalts and andesites.

Reddish-brown latosols in Malaya, Thailand and South Vietnam and a part of the latosols in Cambodia and Indonesia correspond to this group.

13. Red-yellow latosols (oxisol—udox)

Red and yellow latosols in Ceylon, Malaya and South Vietnam, yellow latosols and red latosols in Thailand, the rest of the latosols, except those qualified to be the preceding group, found in Cambodia and Indonesia are included in this group.

14. Organic soils (histosol)

This group includes these soils termed variously as bog soils, half-bog soils, peaty soils, marsh soils, soils of swamps.

Organic soils in Malaya, organosol in Indonesia, peat and muck soils in South Vietnam correspond to this group. Bog and half-bog soils in Ceylon as classified by Moormann and Panabokke are also qualified for the present group.

Dudal and Moormann define this group as containing at least 30% organic matter in a surface layer at least 30 cm thick. Among the so-called half-bog soils there might be soils which are neither qualified for organic soils nor for low humic gley soils. Humic gley soils of the 1949 USDA system seem to be a group to accommodate these soils most adequately.

B. Other soil units which have not so far been correlated

There are still many soil units remaining, especially among those soils of Burma and North Vietnan, which have not been correlated with the great soil groups as defined by Dudal and Moormann. They are presented here in somewhat the following fashion. The authors have taken those countries first, soils of which have been classified according to the USA/FAO system, and has left Burma and North Vietnam until the end, since in both countries the Russian system of classification was used.

In Ceylon and Thailand, a soil unit is separated as *reddish-brown lateritic soils.* Dudal and Moormann regard this as a variety of red-yellow podzolic soils that lacks the A_2 horizon, although the necessity to set up an independent great soil group to accommodate this group was expressed by them.

Rendzinas are excluded here from the original definition of grumusols by Oakes and Thorp. This group appears as an independent soil unit besides grumusols in Ceylon and Thailand, and seems to correspond to the conventional definition of rendzinas. According to Dudal and Soepraptohardjo rendzinas occur also in Indonesia though their distribution may be limited.

A soil unit in Indonesia, *lateritic soils* (17), is difficult to be correlated owing to the lack of reference materials. This may be a soil group having a continuous layer of indurated or pisolitic laterites like *laterite soils* in Malaya as defined by Panton.

Earthy red latosols in South Vietnam are, according to Moormann, akin to reddish-brown latosol, but somewhat different in chemical and physical properties.

Compact brown latosols in South Vietnam are different from the other latosols in color, structure, consistence, etc., and judging from their morphological characteristics Moormann regards this as a transitional group to red-yellow podzolic soils.

Soil units in Cambodia are thought to be on the great soil group and sub-group level and have rather unique names. Correlation of some of the soil units is given by Crocker, as follows:

Plinthite podzols (4) correspond in the most part to grey podzolic soils, with which a part of *red-yellow podzols* (1) is also correlated.

Cultural hydromorphics (5) are a group of soils strongly affected by rice cultivation and it appears difficult to find out an exact equivalent in the ordinary soil literature. A part of them may be included in low humic gley soils.

A part of *plinthitic hydromorphics* (7) may correspond to grey podzolic soils and another part to low humic gley soils.

Brown hydromorphics (8) are a group of hydromorphic soils developed on colluvial materials of mixed basic and acid sources and may in part be included in low humic gley soils.

Alumisols (9) are equivalent to cat clay. It may be asked, however, whether cat clay or acid sulfate soil is qualified for a great soil group or a sub-group. Moormann[17] thinks that separation of this unit should be made on a family or series level. The same question can be applied to some other soil units of Cambodia.

For Burma and North Vietnam the Russian system of soil classification is adopted and a genetic soil type is nearly equivalent to a great soil group.

In Burma the following nine genetic soil types were recognized by Karmanov:
In the humid zone,

1. Light-colored meadow (gleyey) soils
2. Light-colored meadow degraded soils
3. Reddish-yellow soils of monsoon tropical forests
4. Red soils of mountain tropical forests
5. Mountain red-yellow soils

In the dry zone,

6. Dark-colored meadow soils
7. Dark compact soils of dry savanna
8. Red-brown soils of dry savanna
9. Reddish-cinnamon soils of dry tropical forests and bushes

All but light-colored meadow degraded soils appear as the soil units in the map legends.

Light-colored meadow soils develop mostly on alluvial plains. Mechanical compositions and sesquioxide contents are uniform throughout the profile. Therefore this group, especially those mapped in complex with meadow-bog soils and meadow-alluvial soils (legends 2 and 3), appear to correspond mostly to alluvial soils under hydromorphic influence.

Light-colored meadow degraded soils do not appear as a soil unit in the map legends. This group usually occurs on the transitional area from a flood plain to a hilly territory (Rozanov and Rozanova[24]) and is characterized by eluviation-illuviation of both clays and sesquioxides along the profile. Thus this group corresponds most probably to low humic gley soils, and may be included as a part of light-colored meadow soils of the legend 1.

Reddish-yellow soils of monsoon tropical forests are a group of soils occurring in hilly territory and characterized by a weak textural profile and some eluviation of sesquioxides from the surface. In the southern part of Burma this group often has laterite layer in the subsoil. The present group appears to include both red-brown tropical evergreen forest soils and yellow-brown forest soils as classified by Rozanov and Rozanova, both of which usually have high base saturation, 50 % throughout a profile.

Judging from the environmental conditions of occurrence, this group may be best correlated with red-yellow podzolic soil. However, according to the profile characteristics and the analytical data, at least a part of this group can be classed under the alfisol order of the "7 th approximation".

Thus the present group probably includes both typic and alfic variants of red-yellow podzolic soils (or ultisol) and possibly of grey podzolic soils, which are supposed to be distributed on the terraces of the lower Irrawadi region according to Dudal and Moormann.

Red soils of mountain tropical forests develop on relatively level topography of the Shan Plateau (1000-1200 m high) originally derived from limestone. The annual rainfall is about 1500-2000 mm. Clay and sesquioxide distribution along the profile is uniform, but bases are strongly leached. The lateritic soils of Rozanov and Rozanova may correspond to this group. This unit may include reddish-brown latosols and red-yellow latosols.

Mountain red-yellow soils are formed on clay shales and sandstones of mountainous areas under highly humid conditions. No analytical data are available, but this group may correspond to red-yellow podzolic soils.

Dark-colored meadow soils are distributed on flood plains in central Burma where the annual rainfall is around 500-900 mm. Profile development is poor and some influence of salinity can be detected. This group may be included in alluvial soils.

Dark compact soils of dry savanna occur mostly on flat topography of hilly land made up of late tertiary clay shales and sandstones, and also some on alluvium. They are characterized by dark coloration, heavy texture and compactness. Rozanov and Rozanova[25] admit similarity between this group and regurs in India, but do not put them in the same genetic type, because dark compact soils have some solonetzic nature and relics of the past hydromorphic regime.

The present group is, however, best correlated with grumusols.

Red-brown soils of dry savanna occur in the similar environmental conditions as the preceding two groups. Dudal and Moormann put them in red-brown earth-group. Although clay accumulates in the sub-soil, this is, according to Rozanov and Rozanova, due to *in situ* accumulation. According to Karmanov eluviation of sesquioxides from the surface horizon is considerable.

Reddish-cinnamon soils of dry tropical forests may be equivalent to "tropical cinnamon-brown soils" of Rozanov and Rozanova, who regard this group as a deeply-leached sub-group of cinnamon-brown soils of dry shrub forests of the Mediterranean region. Non-calcic brown soils would be the equivalent of the present group.

As for North Vietnam, Fridland sets up two genetic soil types among alluvial soils, *i. e.*,

1. *alluvial flood plain soils*, receiving fresh deposits annually, and
2. *alluvial deltaic soils*, not receiving fresh deposits regularly, the latter being rice paddy soils strongly affected by human activities. These are thought to be mostly alluvial soils (undifferentiated), but a part of the second unit may correspond to low humic gley soils.

Bog soils are another soil type, which can be subdivided into two sub-types, gleyey-bog soils and silty-bog soils. A part of them, especially those under natural vegetation, may correspond to organic soils, but most of the soils may be included in alluvial soils.

Among the subdivisions of the bog and saline soils there is a unit called *acid saline soils* or aluminous soils, which correspond to "sol aluné" or acid sulfate soils.

According to Fridland, *lateritic soils of permanently humid tropical forests* are grouped into four, namely

(a) primitive—appreciable amounts of weatherable minerals,
(b) typical—no weatherable minerals; no laterites; uniform mechanical composition throughout the profile,
(c) soils with differentiated profile, characterized by a lighter mechanical composition in the upper part of the profile,
(d) soils with laterites, having an indurated laterite layer or a great accumulation of concretions.

Group (a) may include brown forest soils, in part, and reddish-brown latosols: map legend 12, *red structured lateritic soils on basic and intermediate igneous rocks*, may correspond to the latter.

Group (b) has the most extensive distribution among the lateritic soils and appears to correspond mostly to red-yellow latosols. Map legend 14, *red and yellow lateritic soils of hilly land*, judging from its distribution on the map, seems to correspond to this group.

Group (c) has a relatively small distribution, according to Fridland. This group appears to correspond to red-yellow podzolic and possibly to grey podzolic soils. Map legend 13, *brownish-yellow structureless soils on older alluvium and dilluvium*, probably satisfies the requisites for the group (c).

Group (d) is chracterized only by the presence of a laterite layer and may be included either in latosols (reddish-brown and red-yellow) or in red-yellow podzolic (or grey podzolic) soils.

Map legend 15, *lateritic soils altered by rice cultivation*, especially degraded ones, may not have exact equivalents. This group will be referred to later.

Among the soils of mountainous areas one can see a certain succession of soils as one goes up higher, *i. e.* lateritic soils—*mountain lateritic soils*—*mountain humic-lateritic soils*—*mountain lateritic-humic soils*. As stated above, at the lower elevation lateritic soils correspond both to latosols and red-yellow podzolic soils, but the higher the elevation, the less intense is the weathering and the more intense is the eluviation from the surface horizon, thus red-yellow podzolic soils may predominate. According to Fridland, mountain lateritic-humic soils show a somewhat lighter color in the surface horizon due to eluviation of iron compounds.

In 1964 to promote the FAO/UNESCO[7] project for the soil map of the world, tentative legends for the world soil map were proposed. The soil units which appear in the legends given for Southeast Asia are the following (the numbers are given according to the FAO publication):

2. Lithosol
3. Regosol
4. Alluvial soil
5. Acid sulfate soil
7. Rendzina
8. Vertisol
9. Brown forest soil
11. Andosol
23. Red-brown mediterranean soil
24. Red-yellow podzolic soil
28. Ferruginous tropical soil

30. Dark red ferralsol
31. Red-yellow ferralsol
34. Podzol
37. Saline soil
    Low humic gley soil
    Grey hydromorphic soil

Vertisol (8) is equivalent to grumusol of Dudal and Moormann. *Red brown mediterranean soil* (23) may include both non-calcic brown soil and red-brown earth. *Red-yellow podzolic soil* (24) includes a part of grey podzolic soil besides red-yellow podzolic soil of Dudal and Moormann. *Ferruginous tropical soil* (28) appears to include alfic variants of grey podzolic soils. *Dark red ferralsol* (30) and *red-yellow ferralsol* (31) are equivalent to dark red and reddish-brown latosol and red yellow latosol, respectively.

Low humic gley soil and *grey hydromorphic soil* would be the equivalents of the group bearing the same name. They are not included in the 37 soil units presently proposed, being probably left for further consideration.

4. Problems in the Classification of Paddy Soils

Among the various land uses in the Southeast Asian countries, rice cultivation in paddy fields is by far the most important, not only because rice is the staple food for the people in the area, but also because of its vital importance in the economy of most countries either as an export or as an import commodity.

For paddy rice cultivation, the soil is leveled and/or terraced and low dikes are prepared around each field to keep the soil waterlogged for at least 3-4 months a year, and many of the cultivation practices are conducted in the waterlogged condition. Therefore, in certain cases continuous rice cultivation brings about considerable changes in the morphology of the soil. Dudal[3] states that soils which have undergone such morphological changes are found commonly in alluvial soils, grumusols, latosols, andosols, regosols, and, though less frequently, in red-yellow podzolic soils, grey hydromorphic soils, planosols and grey-brown podzolic soils.

Among the legends mentioned in Section 2, there are soil units such as the cultural hydromorphics in Cambodia and the lateritic soils altered by rice cultivation in North Vietnam, both of which have definite morphological characteristics brought about by the cultivation of rice.

In this paper, paddy soils that have definite morphological characteristics associated with definite forming processes under rice cultivation are distinguished from paddy field soils in general by putting the former in quotation marks, *i. e.* "paddy soils". Following this, there is a proposal for a new term to replace "paddy soils" to help avoid the confusion arising from the double use of this term.

Since the 1930's, attempts have been made in Japan to classify paddy soils. Kamoshita[10] was the forerunner and he tried to put the paddy soils into Stremme's scheme of classification of "wet soil types". Inspired by the ideas of Uchiyama[29] and Kanno[11] in the early post-war period, Yamazaki,[28] Kanno,[12] Oyama,[20] and the Pedologist Group[22] have made several proposals since 1960. Correlation of the soil units of these authors at the great soil group level is shown on Table 1. Except for Oyama's scheme, in which seven great groups are set up in consideration of seven diagnostic horizons corresponding to each of the great groups, all the others take hydrological conditions as the most important criterium, that is, the presence or absence and intensity of gleyzation due to ground water, reduction of the surface horizon due to irrigation water, and the degree of migration of soil materials due

Table 1 Correlation of the various soil units at the great soil group level for Japanese paddy soils.

Oyama	Yamazaki	Kanno	Pedologist
Peat Soils	Ground Water Soil Type	—	Peat Paddy Soils
Muck Soils			Muck Paddy Soils
Gley Soils	(Gr. gr)	Ground Water Gley Rice Soils (A I)	Ground Water Gley Paddy Soils
	(Gi. gr)	(A II)	Stagno-Water Gley-Like Upland Paddy Soils (in part)
	(Gi. gi)		
Grey Soils	(Ai. gi)	Intermediate Gley-Like Rice Soils (B III)	
	Irrigation Water Soil Type	(B IV)	Surface Water Gley-Like Paddy Soils
	(Ai. a)	Surface Water Gley-Like Rice Soils (C V)	
	(A_1. a)		
Yellowish-Brown Soils	(Ai. b)		Stagno-Water Gley-Like Upland Paddy Soils (in part)
	(A_1. b)		Surface Water Gley-Like Upland Paddy Soils
Black Volcanic Ash Soils	These are separated at the lower categorical levels.		
Brown Volcanic Ash Soils			

to the percolation of surface water.

The processes of the formation of "paddy soils" are defined by Yamazaki as the processes of differentiation of the soil parent material into eluvial A and illuvial B horizons. However, in Table 1, "ground water soil type" is separated, which obviously does not have an illuvial horizon. Thus not only the eluviation-illuviation process but also gleyzation are accounted for in the paddy soil forming process. Kanno and the Pedologists regard as essential processes of paddy soil formation, gleyzation and the mottle-forming process, which would be the result of Yamazaki's eluviation-illuviation process.

Although Oyama's scheme is essentially different from the others and some of his diagnostic horizons are questionable as to whether they are really diagnostic of "paddy soils", he also considers gleyzation and the mottle-formation important in paddy soil formation. Thus it is postulated that there are not many differences among the various recent proposals regarding the basic concept of paddy soil formation, though there are some differences in the technical aspects.

In reviewing these classification schemes, two points related to each other can be questioned. One concerns the relationships of paddy soils to other soils in the general soil classification system, and the other concerns the confusion in the usage of the term *paddy soils*.

The first point can be illustrated by peat and muck paddy soils. These soils may not show the morphological characteristics of "paddy soils", yet they are included in the classification of paddy soils. Then what is the relationship between the peat and muck paddy soils and peat and muck soils (organic soils)? The same question can be applied to ground water gley rice soils with a horizon sequence of gleyed plow layer (A_p G)—gley horizon (G). At the higher categorical levels the features in the sub-surface and sub-soils are usually adopted as the differentiating criteria. Then can one distinguish the ground water gley rice soils from some half-bog soils with similar subsoil characteristics?

The second point is closely related to the first one. The ambiguity in the relationship between paddy soils and other soil groups originates in confusion in terminology. The term *paddy soils* in the sense of paddy field-soils is not always strictly distinguished from the term "paddy soils" as defined in this paper. As stated above most peat and muck paddy soils as well as soils that have undergone only gleyzation are not qualified as "paddy soils" in the general soil classification.

It is necessary here to define the central concept of "paddy soils". Among the soils that have been utilized for rice cultivation for a long time there are those which have one common type of morphological characteristic in spite of a marked difference in the climate and in the parent material; for example, many surface water gley-like or irrigation water type paddy soils developed on alluvium in Japan closely resemble the "sawah" soil developed on a reddish brown latosol, which Koenigs[14] observed in West Java.

Development of these soils is conditioned by downward movement of water, which transports ferrous and manganous ions mobilized in the reductive surface horizon of paddy field soils down to the sub-soil where the more oxidative conditions due to the lesser microbial activity cause precipitation of these ions. Clays often undergo the same eluvial-illuvial process.

Thus the presence of the surface plowed horizon that have undergone reduction-eluviation and the oxidation-illuviation horizon in the sub-surface and sub-soil, is the most essential requisite of the "paddy soils". Presence of ground water-gley horizon is not essential, as in the case of "paddy soils" developed on soils with a low ground water table. Sub-surface ploughpan layer is often encountered in the "paddy soil" profile, but this may be a part of the eluvial A horizon and/or of the illuvial B horizon. Therefore, it is difficult to count a ploughpan as an independent genetic horizon of "paddy soils".

No other soils have been reported which have similar genesis and morphology to the "paddy soils". "Ground water podzol" may be the nearest analogue. However, the presence of ground water is not the essential requisite of "paddy soils", as mentioned above. Eluviation-illuviation process of "podzol" is different from that of "paddy soils" in that oxidation-reduction conditions are not essential in the former.

"Paddy soils" as described above can be qualified for an independent great soil group, because the kind and the sequence of genetic horizons are clearly distingushable from those of other soils of the same categorical level (great soil group level).

Dudal[4] considers that "paddy soils" can be adequately described at the sub-group level and proposes an adjective "antraquic" to be added to the great group name from which "paddy soils" are derived. However, a question arises as to whether it is adequate to describe "paddy soils" with a distinct horizon differentiation as a sub-group of an alluvial soil that is defined as lacking profile development. Moreover, as a sub-group is basically either typic or intergradient, it would be easier to define a sub-group if the typic "paddy soils" are set up at the great (soil) group level.

Karmanov considers that when a qualitatively new process occurs in a soil through cultivation of rice, the soil is qualified for an independent genetic soil type. When a red-brown soil of dry savanna is brought under rice cultivation, essential changes occur in water regime, physical properties, etc., and a qualitatively new process like degradation comes into existence. In this case a new genetic soil type—red-brown *meadow* soil—can be separated. Likewise, in Burma, reddish-yellow *meadow* soils and reddish-cinnamon *meadow* soils are the genetic soil types of paddy fields.

However, when a dark meadow soil is cultivated for rice, changes in the water regime, physical properties, etc., are not marked and only quantitative. In such a case he considers these soils under rice cultivation are not qualified for a new genetic type and should be separated on lower taxonomic levels from the original soils.

According to Fridland[9] it is necessary to separate many types of paddy soils, each of which may be related either to the specificity of the original soil type or to the processes taking place in the soil under rice cultivation, *e. g.* degradation. In North Vietnam he separates the following genetic soil types or groups of genetic soil type ; 1. ferrallitic rice soils, 2. alluvial-littoral rice soils, and 3. marshy rice soils.

However, is it adequate to define as many great soil groups of "paddy soils" as the number of soils from which they are derived? Once different soils are brought under rice cultivation, the superimposed morphology would be one type if conditions are appropriate, *i. e.* the sequence of reduction-eluviation and oxidation-illuviation horizons, irrespective of the differences in the original morphology, as in the case of "sawah" soils in Indonesia and Kanno's surface water gley-like rice soils. Thus the original soils should be regarded as the parent material of the "paddy soils" formed and taken into consideration at the sub-group level. In order to accommodate the many typic "paddy soils" developed in various original great groups, here the typic sub-group should be plural.

Distinctions between the two terms, paddy soils and "paddy soils", are made possible only in writing. A new great soil group name should be adopted to avoid confusion in terminology. The authors' proposal is a new term, "AQUORIZEM" (əkwɔ́rizem), which signifies paddy rice by *aquoriz-* and a great soil group by *-zem*, to replace "paddy soils", thus leaving free the general term, paddy soil to refer to land use.

Classification of aquorizem ("paddy soils") at higher categorical levels of the 1949 USDA system would be as follows : intrazonal order—"agromorphic" suborder. Hydromorphic suborder may not be adequate, because "paddy soils" can develop without hydromorphism, though "inverted gley" (Dudal and Moormann) is observed in the surface horizon during the rice growing season. The single, most important agency which leads to the formation of aquorizem ("paddy soils") is human agricultural activity, and thus the tentatively proposed term "agromorphic" would accommodate soils in the future that show morphological departure from the natural soils under increasingly intensified human agricultural activity.

Lower categories are sub-group, family and series. First of all it is necessary to define the typic "paddy soils" in terms of quantitative attributes before sub-group separations can be made. This is a task to be done.

At the family level properties of agricultural importance, such as the surface soil texture, presence or absence of layers or horizons in the subsoil which may greatly exert influence on the growth of rice, should be considered in view of the fact that "paddy soils" are strictly cultivated soils.

Soils which are cultivated for rice but not fully qualified for "paddy soils" may form a sub-group of the original great soil group. This is concordant with Dudal's proposal. A part of Kanno's intermediate gley-like rice soils may thus be classified as sub-groups of some hydromorphic soils.

Adaptation of the present idea to the "7th approximation" has not as yet been attempted, though the concept of sub-group was borrowed from it. It is another task yet to be undertaken.

5. Summary

Legends of the soil maps of the Southeast Asian countries were presented and the soil units were correlated in terms of the great soil groups as proposed by Dudal and Moormann.

As there are many great soil groups which are utilized for rice cultivation in Southeast Asia, problems associated with the classification of paddy soils were discussed. Because of the confusion in the usage of the term paddy soils and in order to make clearer the relationship of "paddy soils" with other soil groups in the general soil classification system, a new term "Aquorizem" was proposed for this soil group. This new term, "Aquorizem" has as its basic concept, an acquisition of specific morphological characteristics under rice cultivation and it is set up at the great soil group level. Classification of the soil group at both higher and lower categories was also discussed.

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Note:

The "sawah" soil referred to in this paper signifies the particular soil that was described by Koenigs,[14] although in Indonesia the word "sawah" means paddy soils in general.