Diversity of Soils and Soil Management Measures in Tropical and Subtropical Islands

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The tropics and the subtropics are home to numerous and widely distributed islands, that often closely follow patterns of volcanoes and coral reefs. However, there are also islands which consist of not volcanic rocks but of sedimentary or metamorphic rocks, such as the Amami and Ryukyu Islands. Coral reefs have developed on igneous, sedimentary, and metamorphic rocks in these tropical and subtropical islands. Moreover, in the large islands, wide alluvial plains have developed and formed numerous terraces as a result of variations in sea level and upheavals in the Pleistocene.

The climate of the tropical and subtropical islands is generally characterized by high temperatures and high humidity. However, there are numerous islands that are influenced by monsoons, which have different directions in summer and winter, and with severe dry seasons.

Since the climate is not uniform, in addition to variations in geology and topography, the soils are more varied. These different soils and climates have a major influence on local agricultural practices, and have led to various different farming systems.

I describe here the various soils, agriculture and soil management measures for ordinary upland cultivation in the Amami and the Ryukyu (Okinawa) Islands and the Philippine Islands, which are characteristic tropical and subtropical islands.

1. Climate and soil moisture regimes

The Amami and Ryukyu Islands experience a humid subtropical climate with an annual mean temperature of 21 to 24 °C (Fig. 1). Ishigaki Island (where the mean temperature of the coldest month 18.3 °C), situated at the southernmost end of the Ryukyu Islands, is exactly on the boundary between tropical and temperate zones, according to Koeppen's climatic zone categorization, in which the mean temperature of the coldest month of a tropical climate is 18 °C or above.

There is high rainfall in the summer due to *baiu*, or typhoons, in the Amami and Ryukyu Islands, but although rainfall is lower in winter, it exceeds 100 mm monthly, and the climate remains humid (Fig. 2). However, years

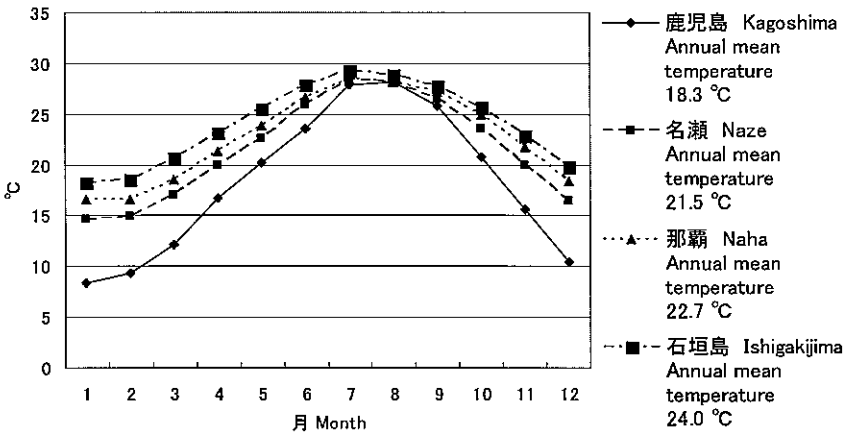

Fig. 1. Temperatures of the Amami and Ryukyu Islands

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without *baiu* or typhoons lead to water shortages. In Kagoshima, which is in the temperate zone, there are three months with rainfall of 100 mm or less in winter.

The area of the Philippine Islands is 300,000 km^2, exactly equal to the area of Japan minus Hokkaido. The annual mean temperature is about 27 °C throughout the islands. The difference between the mean temperature in summer and winter is less than 5 °C, making it a typical oceanic tropical area.

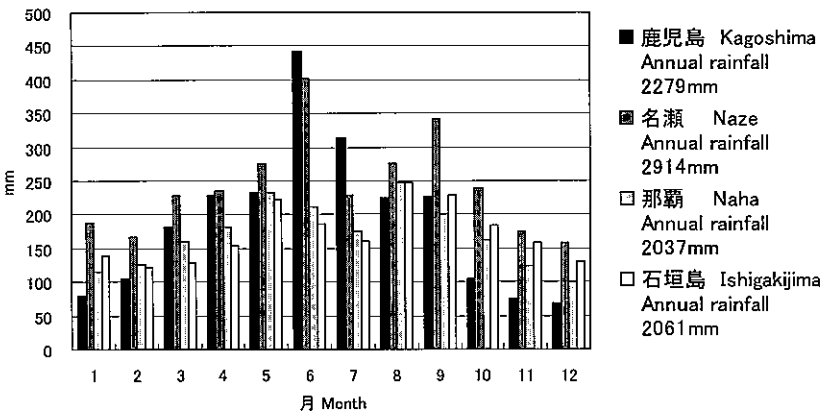

Fig. 2. Rainfall of the Amami and Ryukyu Islands

Although the rainfall in many areas in the Philippine Islands is 1500 to 3500 mm, the annual distribution of rain varies greatly with location because of monsoons that have a wind direction that is different in summer and winter, and typhoons.

The climate type of the Philippine Islands is divided into three, according to the number of dry months: less than two months (Af), two to four months (Am1), and four months or more (Am2). Months with 100 mm or less of rainfall count as dry months. The eastern coasts of the Philippine Islands have a constant tropical rain forest climate (Af) due to monsoons from the northeast in winter and typhoons in summer, and western coasts have a tropical monsoon climate (Am2) which has high rainfall from southwest monsoons and typhoon in summer and a severe long dry season in winter (Fig. 3). The tropical monsoon climate (Am1) is between Af and Am2.

At Daet, in the Bicol region, which has a tropical rain forest climate (Af), there are no months with a rainfall below 100 mm, and there are also no months with a rainfall below the monthly evapotranspiration (Fig. 4). On the other hand, at Laoag, in the Ilocos region, which has a tropical monsoon climate (Am2), eight months have monthly rainfall of 100 mm or less, and six months or more have a monthly rainfall below the monthly evapotranspiration . At Los Banos, in Laguna province, which has a tropical monsoon climate (Am1) that is midway between the two above examples, four months have a monthly rainfall of 100 mm or less, and three months have a monthly rainfall below monthly evapotranspiration.

Thus, in comparatively large tropical islands, different rainfall patterns are made by monsoons and typhoons, which have had a significant influence on soil and agriculture.

Soil moisture regimes are divided, according to the number of dry soil days, into perudic (less than 30 days); udic (30 to 90 days); ustic (90 to 180 days); and aridic (180 days or more). A dry soil day is a day when the moisture of the soil that supports plant roots becomes dryer than pF4.2, the permanent wilting point. Although the soil moisture regime is exclusively perudic in the Amami and Ryukyu Islands, it is divided into four categories in the Philippine Islands.

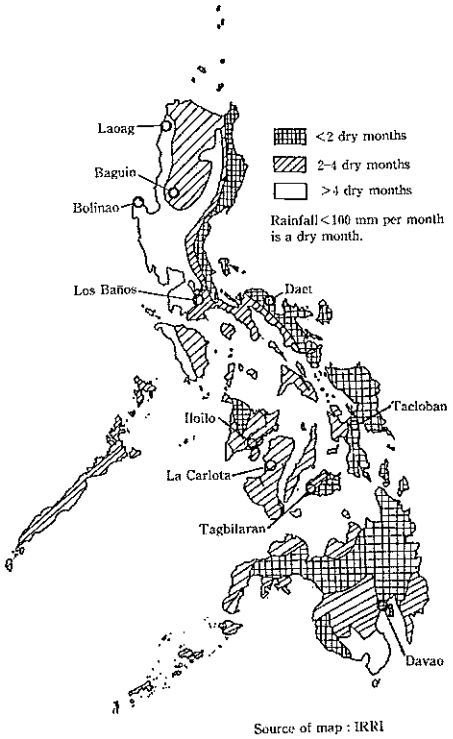

Fig. 3. Climate types of the Philippine Islands

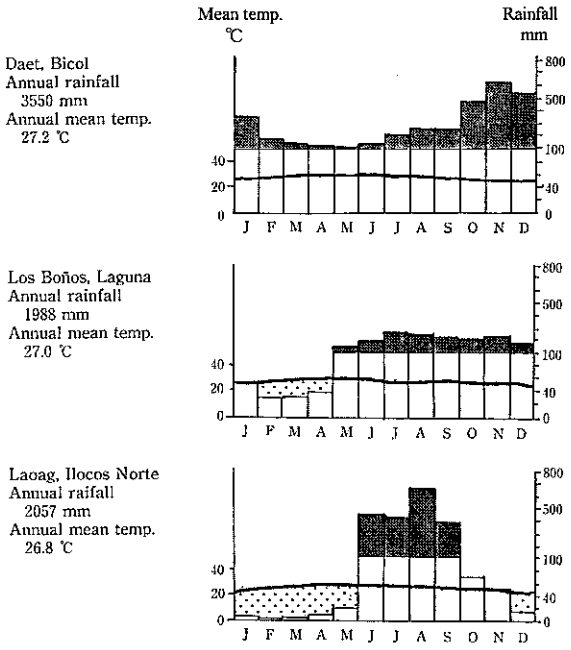

Fig. 4. Temperature and rainfall in the Philippine Islands

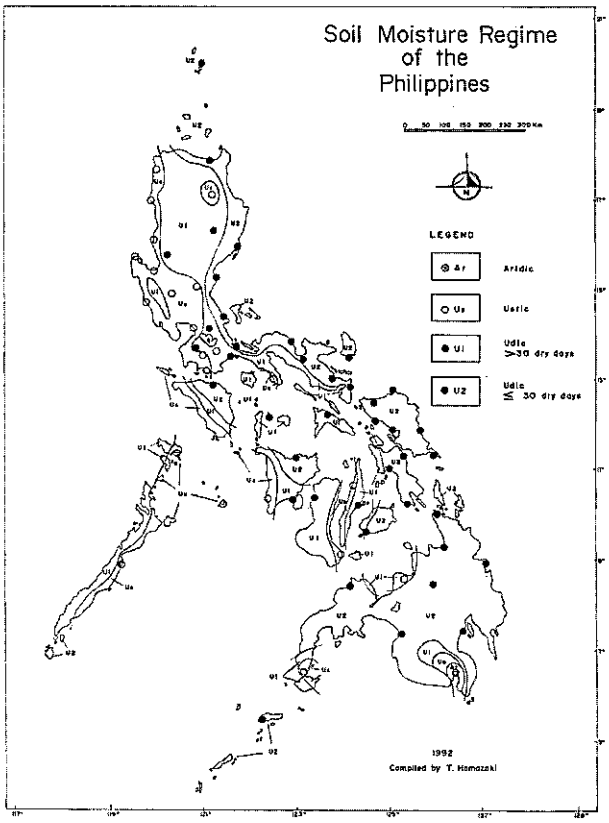

Fig. 5. Soil moisture regime of the Philippine Islands

The soil moisture regime of the Philippine Islands is generally perudic (U2) on the eastern coasts of every island, including Mindanao Island, and ustic (Us) on the western coasts of every island, except for Mindanao Island. The udic soil moisture regime (U1) is between these two types, and an aridic soil moisture regime (Ar) also occurs at the very narrow part near General Santos in the southern part of Mindanao island.

The dryness of soil has a great influence on pedogenesis, and common crops cannot be grown at all without irrigation during dry days. Soil dryness has a major influence on agriculture in the Philippine Islands.

2. Soils

The correlation between soil classification names currently used in Japan and those currently used worldwide is shown in Table 1, since various soil classification names are used globally that are unknown to non-specialists. There are local names of soils in Okinawa but the soil classification of FAO-Unesco, WRB, or Soil taxonomy is used internationally.

The soil profiles and percentage of area by soil group in agricultural lands on the Amami and Ryukyu Islands are shown in Figs. 6 and 7.

There are Brown Forest soils (Cambisols or Inceptisols) and Red-Yellow soils (Alisols or Acrisols, or Ultisols) in the Amami

Table. 1. Correlation of Japanese soil classification with Okinawan local soil classification, FAO system or WRB, and Soil taxonomy

日本の一般名 Japanese Soil Classification	沖縄の地方名 Okinawa Local Soil Classification	FAO分類または 世界土壌資源照合基準 FAO or WRB (1998)	土壌タクソノミー Soil Taxonomy (1999)
赤・黄色土 Red-Yellow soils	国頭マージ Kunigami-mahji	アリソルまたはアクリソル Acrisols or Alisols	アルティソル Ultisols
		(カンビソル) (Cambisols)	(インセプティソル) (Inceptisols)
暗赤色土 Dark Red soils	島尻マージ Shimajiri-mahji	ルビソル Luvisols	アルフィソル Alfisols
		(カンビソル) (Cambisols)	(インセプティソル) (Inceptisols)
黒ボク土 Andosols		アンドソル Andosols	アンディソル Andisols
バーティソル Vertisols		バーティソル Vertisols	バーティソル Vertisols
石灰質陸成未熟土 Carcaric Terrestrial Regosols	ジャーガル Jahgaru	レゴソル Carcaric Regosols	エンティソル Entisols
沖積土 (低地土) Alluvial soils (Lowland soils)		フルビソル Fluvisols	エンティソル Entisols
		(カンビソル、グライソル) (Cambisols or Gleysols)	(インセプティソル) (Inceptisols)

and Ryukyu Islands as zonal soils. These types are found worldwide corresponding to climate or vegetation. There are Dark Red soils (Luvisols or Cambisols, or Alfisols or Inceptisols) as intrazonal soils, strongly influenced by their parent material. There are also calcaric Terrestrial Regosols (Calcaric Regosols or Entisols) which derive from marl and alluvial soils (Fluvisols or Entisols) as azonal soils. In the Ryukyu Islands, Red-Yellow soils were locally called 'Kunigami-mahji', Dark Red soils 'Shimajiri-mahji', calcaric Terrestrial Regosols 'Jahgaru', and they have been treated as problem soils since ancient times. The southern limit of distribution of Brown Forest soils is in the mountain land of Amami-Oshima. The distribution of calcaric Terrestrial Regosols is mostly restricted within the southern part of the main Okinawa island. Red-Yellow soils are derived from non-calcareous parent materials, and Dark Red soils develop on coral limestone terraces. Although alluvial soils are distributed on every island, the characteristics vary with the difference in parent materials.

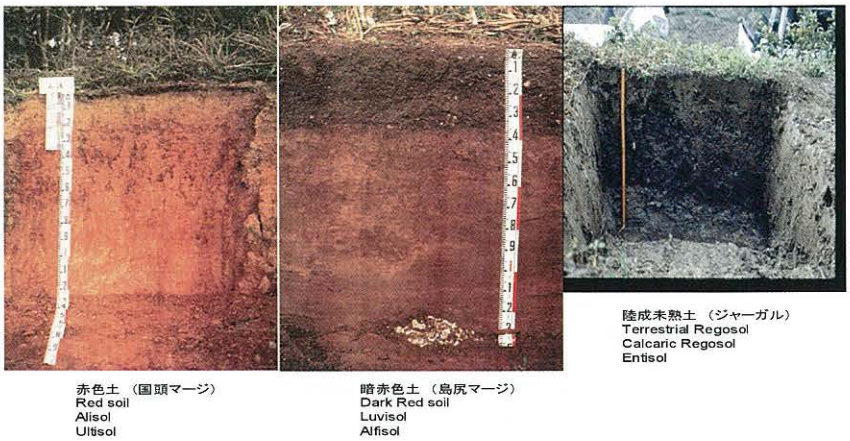

Fig. 6. Profiles of the soils in the Amami and Ryukyu Islands

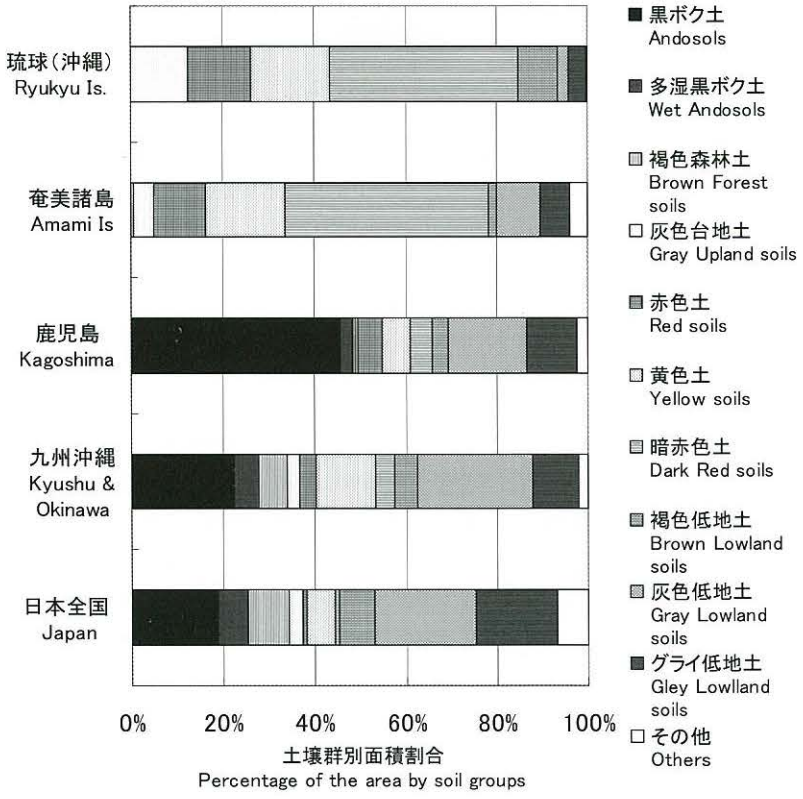

Fig. 7. Percentage of the area by soil groups in agricultural land of the Amami and Ryukyu Islands

As for the distribution percentage by soil group of the agricultural lands in the Amami Islands and the Ryukyu Islands, Dark Red soils occupy 45% and 41%, Red-Yellow soils 28% and 31%, Terrestrial Regosols 4% and 13%, respectively, and alluvial soils, etc., occupy the others. Compared with the whole of Kagoshima Prefecture or the whole of Japan, the percentage of Red-Yellow soils and Dark Red soils is high, and the percentage of Andosols and alluvial soils is low in the Amami and Ryukyu Islands.

The soil profiles and the percentage of areas occupied by soil groups in agricultural lands of the Philippine Islands are shown in Figs. 8 and 9.

Red-Yellow soils (Acrisols, Alisols, Nitosols or Ultisols) are distributed over the Philippine Islands as zonal soils. As intrazonal soils, Dark Red soils (Luvisols or Cambisols, or Alfisols or Inceptisols), Andosols (Andosols or Andisols), and Vertisols (Vertisols) have developed. Vertisols have a thick dark-colored topsoil consisting of montmorillonitic clay, made by repeated swelling and shrinking of the soil by alternation between the dry season and the rainy season. They are therefore also called tropical black

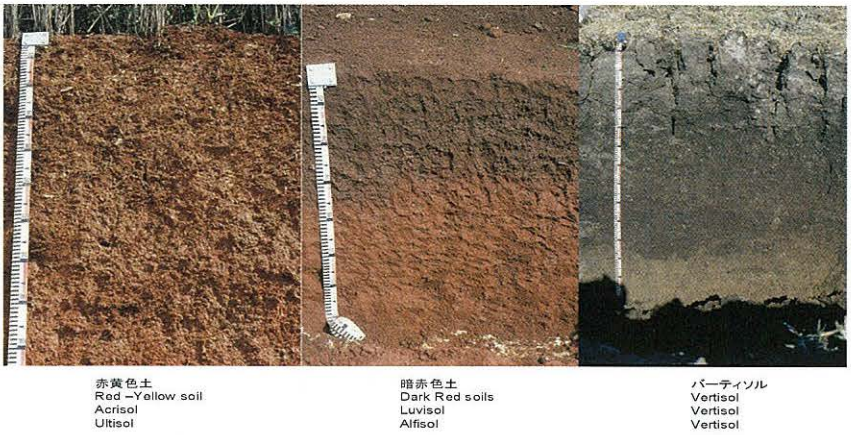

Fig. 8. Soil profiles of the soils in the Philippine Islands

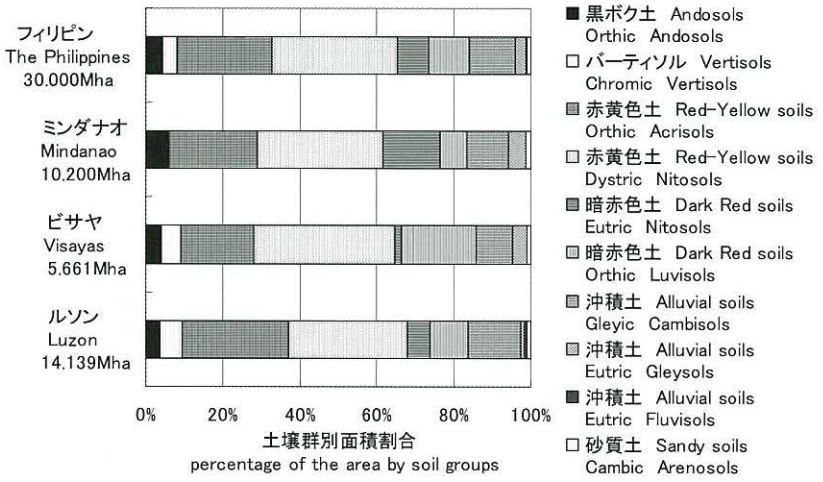

Fig. 9. Percentage of the area by soil groups in whole lands of the Philippine Islands

soils. In addition, alluvial soils (Gleysols, Cambisols, or Fluvisols, or Inceptisols or Entisols) with various characteristics are distributed widely in the Philippine Islands as azonal soils.

Concerning the distribution percentages of soils in the Philippine Islands, Red-Yellow soils, Dark Red soils, Andosols, and Vertisols account for 57%, 19%, 5%, and 4%, respectively.

Thus, the kinds and the distribution rates of the soils in the Amami and Ryukyu Islands and the Philippine Islands are similar.

Some characteristics of each soil are now described. The soil data of the Amami and Ryukyu Islands is based on the results of a soil survey carried out by a soil conservation project on the main Okinawa island. The data of the Philippine soils use the database of Hamazaki *et al.*

The value of pH (H_2O) is in the slightly alkaline range of 7.5-8.0 in Terrestrial Regosols and Vertisols. It is in the neutral to slightly acid range of 6.3-7.2 in Dark Red soils, in the strongly acid range of 4.8-4.9 in Red-Yellow soils, and in the strongly to moderately acid range of 4.9-5.4 in Andosols (Fig. 10). The base saturation percentage is 100% or more in Terrestrial Regosols and Vertisols, 50% or more in Dark Red soils, and 50% or less in Red-Yellow soils and Andosols (Fig. 10).

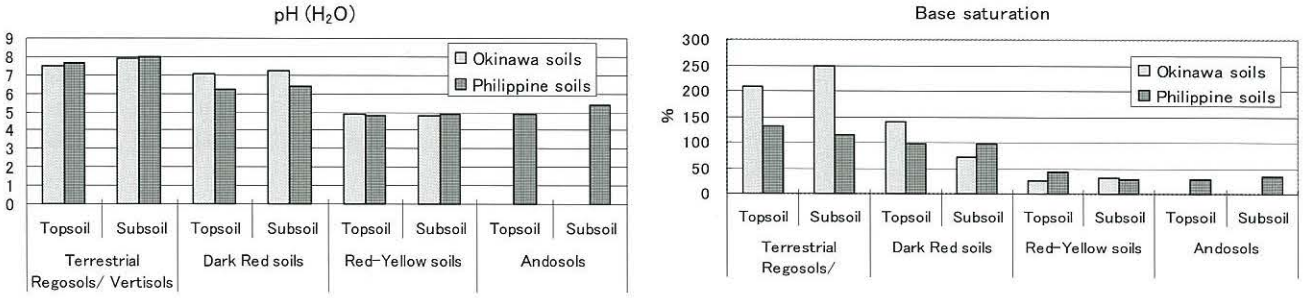

Fig. 10. pH (H_2O) and base saturation of Okinawan and Philippine soils

The clay content is generally as high as 25 to 70%, except for Andosols. In the subsoils of Dark Red soils and Red-Yellow soils of the Philippines, they reach 60-70% (Fig. 11).

Furthermore, compared with the topsoil, clay content is high in subsoils. This tendency is more marked in Philippine soils than in Okinawan soils, and it has been suggested that clay illuviation has taken place to a greater extent in the Philippine soils (Fig. 11). Compared with the Okinawan soils, the argillation and the clay illuviation of the Philippine soils have progressed more.

The value of cation exchange capacity (CEC) is conspicuously high in montmorillonitic Vertisols at 50-60 me/100 g soil (Fig. 12). The CEC value of the calcaric Terrestrial Regosols, which consist of the same clay minerals, is also comparatively high. Although it is 30 me/100 g soil or less in the other soils, it is higher in Philippine soils than in Okinawan soils, reflecting the clay content and the organic matter content. The CEC per 100 g of clay serves as an index showing the degree of aging of the soil. It is clearly lower in the Red-Yellow soils of the Philippines than those of Okinawa, and has become 24 me/100 g or less, which is the standard which divides the soils aged in the subsoil. The value is average. Many actual Red-Yellow soils of Okinawa are Alisols, and the CEC values of the clay are higher than 24 me/100 g. While many actual Red-Yellow soils of the Philippines are Acrisols, and the CEC values of the clay are lower than 24 me/100 g.

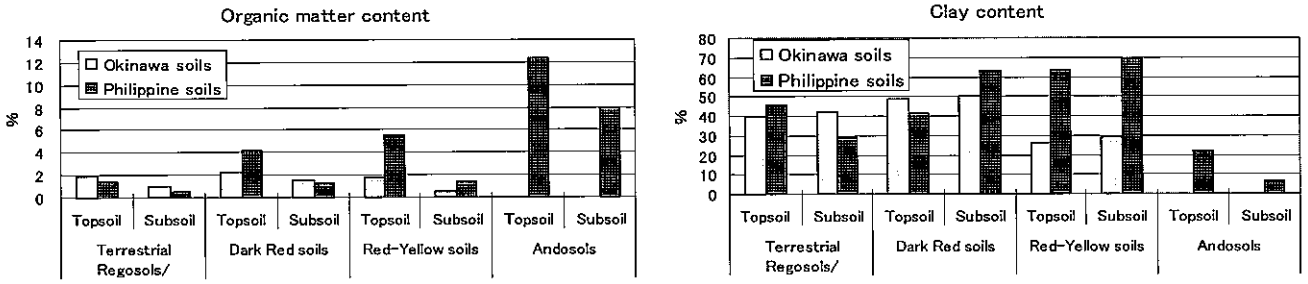

Fig. 11. Organic matter and clay content of the Okinawan and Philippine soils

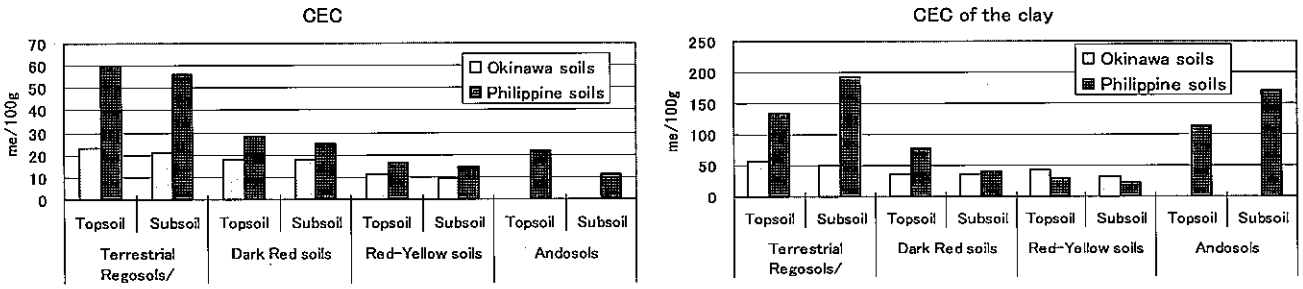

Fig. 12. CEC of the soil and clay of the Okinawan and Philippine soils

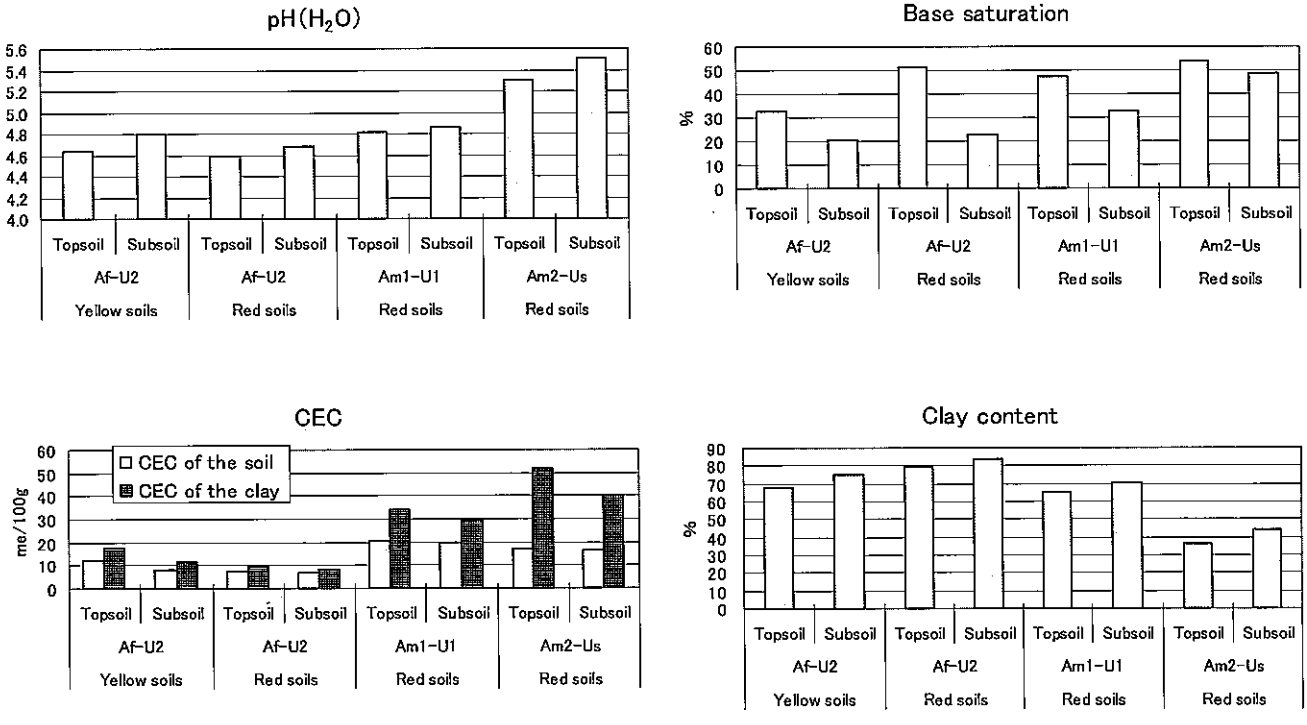

Fig. 13. Change of characteristics in the dry month period in the Red-Yellow soils of the Philippines

In the Philippine Islands, the difference in the climate type is dictated by the difference in length of the dry season. Changes also take place in soil due to differences in climatic type. In Red-Yellow soils, the rate of Red soils becomes higher and the pH values of soils and the base saturation percentage of the subsoils rise with increasing length of the dry season (Fig. 13). Moreover, although the clay content decreases, the CEC value of the clay increases, suggesting that argillation and aging of soil progress more as with shorter dry seasons.

3. Agriculture

The output of agricultural products of Okinawa Prefecture comprises 20% for sugarcane, 16% for flowering plants (chrysanthemums, etc.), 13% for vegetables (string beans, bitter gourd, cabbage, lettuce, etc.), 5% for tobacco, 1.9% for mangoes, 1.3% for pineapples, 1.2% for potatoes (potato, sweet potato, etc.), (Fig. 14). Rice accounts for only 0.8%.

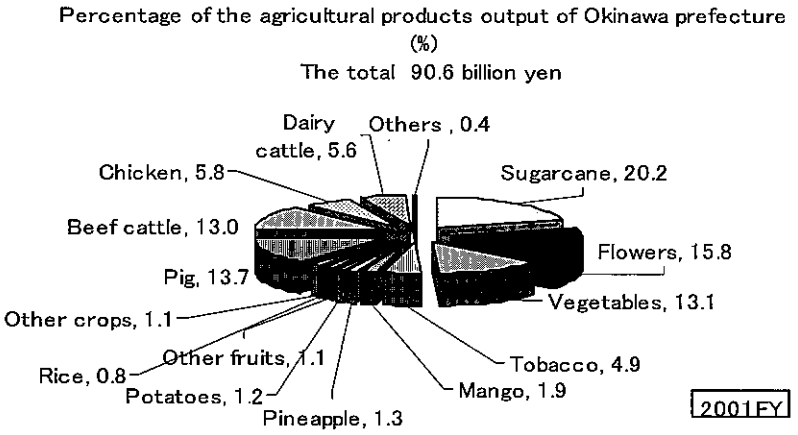

Fig. 14. Percentages of agricultural product output of Okinawa Prefecture

Agricultural land in the Philippines totals 12,237,000 ha. The percentages of planting areas for common crops in the Philippines are 29% for corn, 28% for rice, 3.5% for potatoes (potato, sweet potato etc.), 2.7% for bananas, 1.2% for coffee, 0.5% for vegetables, 0.5% for pineapples, 0.4% for peanuts, 0.4% for mangoes, 0.1% for cacao, 0.8% for other fruit trees and nuts, etc. (as of 1986: Fig. 15). For commercial crops, it is 27% for coconuts, 2.9% for sugarcane, 1.3% for abaca (Manila hemp), 0.5% for tobacco, etc. There are many cultivation areas in the Philippines of corn and rice, which are staples, as well as coconuts. Although sugarcane, pineapple, tobacco, etc. are crops found in both the Philippines and Okinawa, coconut, abaca, coffee, cacao, cashews, etc. is not produced in Okinawa.

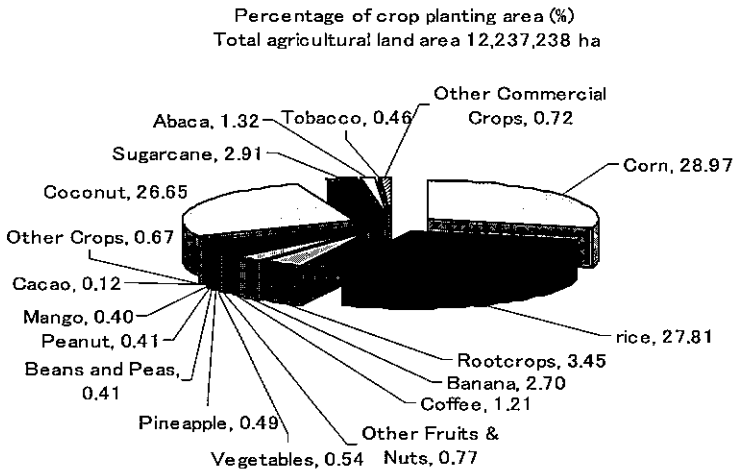

Fig. 14. Percentage of crop planting area in the Philippines

In the Philippine Islands, a major difference is in the length of the dry season and soil moisture regime by area. The difference has greatly influenced the agricultural crops selected.

The crops in the Ilocos region, which has a severe dry season or ustic soil moisture regime, and the Bicol region, which experiences heavy rainfall throughout the year and has a perudic soil moisture regime, are compared here. Since the agricultural land area is much larger in the Bicol region than in the Ilocos region, the comparison is made between the percentage of planting ar

In common crops, the percentage of planted areas of fruit trees, nuts, vegetables, legumes, and peanuts is clearly high in the Ilocos region and low in the Bicol region (Fig. 16). The planting area percentage of corn is also high in the Ilocos region. On the other hand, the planting area percentage of commercial crops shows a significant difference between the Bicol and Ilocos regions (Fig. 16).

As for fruit trees and nuts, bananas, mangoes, citrus, cashews, watermelons, and grapes are grown at an overwhelmingly high rate in the Ilocos region; in contrast, mangoes, cashews, watermelons, and grapes are little grown in the Bicol region while pineapple is grown at a high rate in the Bicol region, and jackfruit in both regions (Fig. 17). Concerning root crops, cassava, camote (sweet potato), and gabi (taro) are grown at a high rate in the Bicol region; sweet potato is grown also in the Ilocos region.

As for vegetables, tomatoes, eggplant, garlic, cabbage, onion, and potato are grown at a high rate in the Ilocos region, whereas tomato and eggplant are rarely grown in the Bicol region (Fig. 18). In commercial crops, coconut and abaca are grown at an overwhelmingly high rate in the Bicol region while abaca is not grown at all in the Ilocos region (Fig. 18). On the other hand, tobacco is grown at a overwhelmingly high rate in the Ilocos region, but not in the Bicol region.

Thus, the length of the dry season or the soil moisture regime has a great influence on the diversity of planted crops. Having a dry season induces diversity in planted crops and the lack of a dry season restricts which crops can be grown.

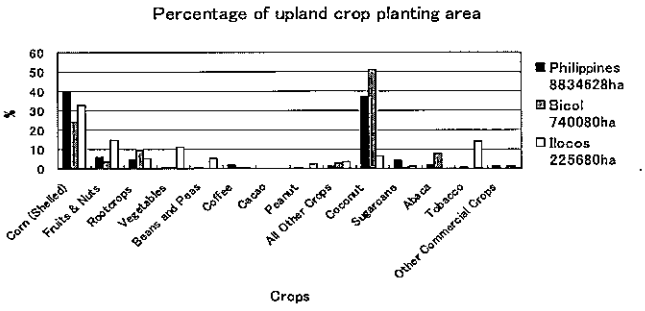

Fig. 16. Upland crop planting area in the Philippines and Philippine soils

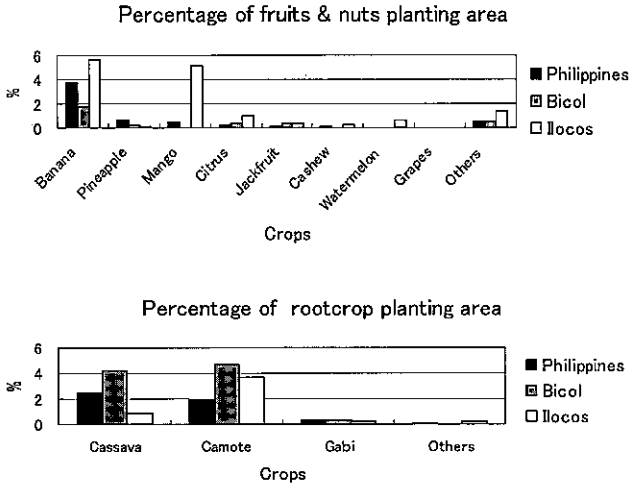

Fig. 17. Fruits and nuts, and root crop planting area in the Philippines

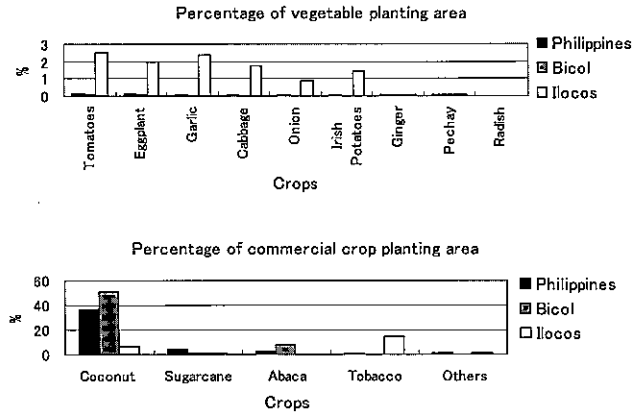

Fig. 18. Vegetable and commercial crop planting area in the Philippines

4. Land Use Guidelines and Soil Management Measures by Land Groupings

Soil productive capability classification for different land use of sites representing the main land grouping was performed, and soil management measures for upland field use with the guideline for different land uses are shown in Tables 2, 3 and 4. Land grouping is a classification of land which combines soil type, topography, parent material, climate, and soil moisture regime. Soil productive capability classification for different land uses, such as upland fields, orchards, and grassland was performed, and guidelines for land use were set up. Soil productive capability classification was evaluated and classified according to the slope of the land, water resistance of soil, moisture conditions of soil such as drought and waterlogging, the physical

properties of the soil, such as effective depth of soil and ease of plowing, and chemical properties of soil such as inherent fertility and levels of available nutrients. Soil management measures can be designed for every land use in each land grouping, since factors leading to the limitations, hazards or risk of soil damage for crop production have become evident as a result of soil productive capability classification. Here, soil management measures for only upland field use are shown.

Table. 2. Productive capability classification, guidelines for land use and soil management measures by land grouping in the Philippine Islands (1)

Land Grouping					Land use (main current crop) U: Upland field O: Orchard G: Grassland P: Paddy field	Soil productive capability classification *2 s: Slope e: Erosion w: Waterlogging dr: Drought d: Effective depth of soil p: Ease of plowing f: Inherent fertility n: Available nutrients							Guidelines for land use by land grouping (Note: Since a supply of nitrogen is required for every land grouping, it has not been prescribed here.)	Soil management measures for upland field use *3 e: Mixed cropping/ Terracing d: Drainage i: Irrigation dp: Deep plowing o: Organic matter l: Liming f: Fertilizer /Fallow					
Site	Soil group	Land form	Parent material	Climate-Soil moisture regime*1		s	e	w	dr	d	p	f	n		e	d	i	d p	o	l	f
BC2	Red soil	Hill, upper and middle terrace	Andesite and basalt residual, old	Af-U2	U (Shifting cultivation, Camote)	Ⅲ	Ⅳ	Ⅰ	Ⅱ	Ⅰ	Ⅱ	Ⅲ	Ⅲ	Numerous barriers to upland field use because of severe soil erodibility, low nutrient holding capacity, and poor nutrient levels. Potential for orchard use with vegetative culture. Strongly acid.	◎		△		○	○	○
					O (Coconut, Banana)	Ⅰ	Ⅱ	Ⅰ	Ⅰ	Ⅰ	Ⅱ	Ⅱ	Ⅲ								
					G (Cogon)	Ⅰ	Ⅰ	Ⅰ	Ⅰ	Ⅰ	Ⅱ	Ⅲ	Ⅲ								
LY4			alluvial, volcanic mud	Am1-U1	U	Ⅱ	Ⅲ	Ⅰ	Ⅳ	Ⅰ	Ⅰ	Ⅲ	Ⅲ	Numerous barriers to upland field use because of severe soil erodibility, poor nutrient levels and impossibility of planting during the dry season. Potential for orchard use with vegetative culture. Moderately acid.	○		◎		○	○	○
					O (Coconut)	Ⅰ	Ⅰ	Ⅰ	Ⅲ	Ⅰ	Ⅰ	Ⅱ	Ⅲ								
					G (Cogon)	Ⅰ	Ⅰ	Ⅰ	Ⅳ	Ⅰ	Ⅰ	Ⅲ	Ⅳ								
IL4			flow sediment	Am2-Us	U	Ⅲ	Ⅳ	Ⅰ	Ⅳ	Ⅰ	Ⅱ	Ⅱ	Ⅲ		◎		◎		△	○	○
					O (Cashew)	Ⅰ	Ⅱ	Ⅰ	Ⅲ	Ⅰ	Ⅱ	Ⅱ	Ⅲ								
					G (Cogon)	Ⅰ	Ⅰ	Ⅰ	Ⅳ	Ⅰ	Ⅱ	Ⅱ	Ⅲ								
BC3	Yellow soil			Af-U2	U (Shifting cultivation, Camote)	Ⅲ	Ⅳ	Ⅰ	Ⅰ	Ⅰ	Ⅱ	Ⅲ	Ⅲ	Numerous barriers to upland field use because of severe soil erodibility, low nutrient holding capacity, and poor nutrient levels. Potential for orchard use with vegetative culture. Strongly acid.	◎				○	○	○
					O (Coconut, Banana)	Ⅰ	Ⅱ	Ⅰ	Ⅰ	Ⅰ	Ⅱ	Ⅱ	Ⅲ								
					G	Ⅰ	Ⅰ	Ⅰ	Ⅰ	Ⅰ	Ⅱ	Ⅲ	Ⅲ								
BC6		Lower terrace		Af-U2	U	Ⅰ	Ⅱ	Ⅱ	Ⅰ	Ⅰ	Ⅱ	Ⅱ	Ⅲ	Potential for upland field use, if soil erosion preventive measures, soil improvement with organic matter and lime, and nutrient supply are performed, though nutrient holding capacity is small. Moderately acid.	△	△			△	○	○
					O (Coconut, Pineapple)	Ⅰ	Ⅰ	Ⅰ	Ⅰ	Ⅰ	Ⅱ	Ⅱ	Ⅲ								
					G	Ⅰ	Ⅰ	Ⅰ	Ⅰ	Ⅰ	Ⅱ	Ⅱ	Ⅲ								
DV1	Dark Red soil (Red-dish)	Lime-stone hill and terrace	Residual, aquatic and/or aeolian deposit on limestone	Af-U2	U (Corn, Peanut)	Ⅰ	Ⅱ	Ⅰ	Ⅱ	Ⅲ	Ⅱ	Ⅰ	Ⅱ	Suitable for upland field use, if soil erosion preventive measures, improvement of water-holding capacity and supply of phosphorous are performed. Slightly acid.	△		△	○	△	△	△
					O (Coconut)	Ⅰ	Ⅰ	Ⅰ	Ⅰ	Ⅲ	Ⅱ	Ⅰ	Ⅱ								
					G	Ⅰ	Ⅰ	Ⅰ	Ⅰ	Ⅰ	Ⅱ	Ⅰ	Ⅱ								
BH7				Am1-U1	U (Corn)	Ⅰ	Ⅰ	Ⅰ	Ⅲ	Ⅱ	Ⅱ	Ⅰ	Ⅱ	Suitable for upland field use, if improvement of water-holding capacity and supply of phosphorus are performed. Irrigation required in the dry season. Slightly acid.			○	△	△	△	△
					O	Ⅰ	Ⅰ	Ⅰ	Ⅱ	Ⅱ	Ⅱ	Ⅰ	Ⅱ								
					G	Ⅰ	Ⅰ	Ⅰ	Ⅲ	Ⅰ	Ⅱ	Ⅰ	Ⅱ								
PN1				Am2-Us	U (Camote)	Ⅰ	Ⅰ	Ⅰ	Ⅳ	Ⅰ	Ⅱ	Ⅱ	Ⅲ	Suitable for upland field use, if supply of nutrients, especially phosphorus and potassium, is performed. Irrigation required in the dry season. Slightly acid.			◎	△	△	○	○
					O (Cashew, Coconut)	Ⅰ	Ⅰ	Ⅰ	Ⅲ	Ⅰ	Ⅱ	Ⅱ	Ⅲ								
					G	Ⅰ	Ⅰ	Ⅰ	Ⅳ	Ⅰ	Ⅱ	Ⅱ	Ⅲ								
BH1	Dark Red soil (Yel-lowish)			Am1-U1	U (Corn)	Ⅰ	Ⅰ	Ⅰ	Ⅲ	Ⅲ	Ⅱ	Ⅰ	Ⅱ	Potential for upland field use, although effective depth of soil is shallow. Irrigation required in the dry season. Slightly acid.			○	○	△	△	△
					O	Ⅰ	Ⅰ	Ⅰ	Ⅱ	Ⅲ	Ⅱ	Ⅰ	Ⅱ								
					G	Ⅰ	Ⅰ	Ⅰ	Ⅲ	Ⅱ	Ⅱ	Ⅰ	Ⅱ								
PN4				Am2-Us	U	Ⅰ	Ⅰ	Ⅰ	Ⅳ	Ⅰ	Ⅱ	Ⅰ	Ⅲ	Potential for upland field use, if supply of nutrients, especially phosphorus and potassium, is performed. Irrigation required in the dry season. Slightly acid to neutral.			◎		△	○	○
					O (Cashew, Guava)	Ⅰ	Ⅰ	Ⅰ	Ⅲ	Ⅰ	Ⅱ	Ⅰ	Ⅲ								
					G	Ⅰ	Ⅰ	Ⅰ	Ⅳ	Ⅰ	Ⅱ	Ⅰ	Ⅲ								

*1, *2, *3: See Table 3.

Table. 3. Productive capability classification, guidelines for land use and soil management measures by land grouping in the Philippine Islands (2)

Land Grouping					Land use (main current crop) U: Upland field O: Orchard G: Grassland P: Paddy field	Soil productive capability classification *2 s: Slope e: Erosion w: Waterlogging dr: Drought d: Effective depth of soil p: Ease of plowing f: Inherent fertility n: Available nutrients								Guidelines for land use by land grouping (Note: Since supply of nitrogen is required for every land grouping, it has not been prescribed here.)	Soil management measures for upland field use *3 e: Mixed cropping/ Terracing d: Drainage i: Irrigation dp: Deep plowing o: Organic matter l: Liming f: Fertilizer /Fallow						
Site	Soil group	Land form	Parent material	Climate-Soil moisture regime*1		s	e	w	dr	d	p	f	n		e	d	i	dp	o	l	f
IL8	Vertisol	Recent alluvial plain	Calcareous alluvial deposit	Am2-Us	U (Tobacco)	I	I	III	IV	I	III	I	II	Suitable for upland field use if improvement of ease of plowing and irrigation in the dry season are performed. Water-holding capacity is high. Good for paddy field use in the rainy season. Neutral to moderately alkaline.		○	◎		○	△	△
					O	I	I	III	III	I	III	I	II								
					G	I	I	III	III	I	III	I	II								
					P (Rice)																
DV3	Brown Lowland soil	Recent alluvial terrace		Af-U2	U	I	II	I	I	I	II	I	I	Best for upland field use. Soil erosion preventive measures required. Neutral.	△				△		
					O (Banana)	I	I	I	I	I	II	I	I								
					G	I	I	I	I	I	II	I	I								
IL3				Am2-Us	U (Tobacco, Peanut, Corn, Mung bean)	I	I	I	IV	I	I	I	III	Best for upland field use. Irrigation in the dry season and phosphorus supply are required. Water-holding capacity is high. Neutral to moderately alkaline.			◎			○	○
					O	I	I	I	III	I	I	I	III								
					G	I	I	I	IV	I	I	I	III								
BC8			Non-calcareous alluvial deposit	Af-U2	U	I	II	I	I	I	I	II	III	Potential for upland field use, if soil erosion preventive measures, and supply of lime and nutrients, especially phosphorus, are performed. Moderately acid.	△				△	○	○
					O (Coconut)	I	I	I	I	I	I	II	III								
					G	I	I	I	I	I	I	II	III								
NG2				Am1-U1	U (Vegetable)	I	I	I	III	II	I	I	II	Suitable for upland field use, if nutrient supply is performed. Irrigation required in the dry season. Moderately acid.			○	△		△	△
					O	I	I	I	II	I	I	I	II								
					G	I	I	I	III	I	I	I	II								
LY2	Gray Lowland soil	Recent alluvial plain		Af-U2	U (Corn, Camote)	I	I	I	I	I	I	I	III	Suitable for upland field use if phosphorus supply is performed. Moderately to slightly acid.						○	○
					O	I	I	I	I	I	I	I	III								
					G	I	I	I	I	I	I	I	III								
LG1				Am1-U1	U (Cabbage)	I	I	II	III	I	II	I	II	Suitable for upland field use. Irrigation required in the dry season. Water holding property is high. Good for paddy field use in the rainy season. Moderately to slightly acid.		△	○		△	△	△
					O	I	I	II	II	I	II	I	II								
					G	I	I	I	II	I	II	I	II								
					p (Rice)																

*1) Climate type; Af: Tropical rain forest (<2 dry months), Am1: Tropical monsoon (2-4 dry months), Am2: Tropical monsoon (>4 dry months).
Soil moisture regime; U2: Perudic (<30 dry days), U1: Udic (30-90 dry days), Us: Ustic (90-180 dry days).

*2) Class; I: Land has almost no limitation or hazard, II: Land has some limitations or hazards and some improvement practices are required, III: Land has many limitations or hazards and fairly intensive improvement practices are required, IV: Land has greater natural limitations or hazards than those in class III but can be cultivated for some crops under careful management.

*3) Necessity of soil management measures; ◎: Essential, ○: Major, △: Some.

Except the land on the flat lower terrace, the land grouping of Red-Yellow soils derived from andesitic and basaltic parent materials on hills and terraces, which has the largest distribution in the Philippine Islands, has serious problems related to the water resistance of the soil, its physical and chemical properties, and the soil moisture conditions for crop production, and is unsuitable for upland field use (Table 2). This land is, however, suitable for orchard use as vegetative culture. Many are actually used as coconut, banana, cashew, and pineapple orchards. If this land is treated as an upland field, soil erosion preventive measures by mixed cropping, terracing, mulching, etc., soil improvement by the application of organic matter and lime, and the improvement of soil fertility by the enrichment of nutrient holding capacity and fertilization or leaving fallow are necessary, and irrigation is essential for cropping in the dry season. These measures for soil and field improvement are immensely costly.

Table. 4. Productive capability classification, guidelines for land use and soil management measures by land grouping in Okinawa

Land Grouping					Land use (main current crop) U: Upland field O: Orchard G: Grassland P: Paddy field	Soil productive capability classification *2 s: Slope e: Erosion w: Waterlogging dr: Drought d: Effective depth of soil p: Ease of plowing f: Inherent fertility n: Available nutrients								Guidelines for land use by land grouping (Note: Since supply of nitrogen is required for every land grouping, it has not been prescribed here.)	Soil management measures for upland field use *3 e: Mixed cropping/ Terracing d: Drainage i: Irrigation dp: Deep plowing o: Organic matter l: Liming f:: Fertilizer /Fallow						
Site	Soil group	Land form	Parent material	Climate-Soil moisture regime*1		s	e	w	dr	d	p	f	n		e	d	i	dp	o	l	f
Gsk/ Nkg	Red soil	Hill and terrace	Sedimen-tary rock residual, old alluvial, sediment	Cf-U2	U (Pineapple, Sugarcane)	II	III	I	II	II	III	III	III	Numerous barriers to upland field use because of severe soil erodibility, poor nutrient levels, etc. Strongly acid.	○		△	△	○	○	○
Amd/ Yr	Yellow soil				U (Pineapple, Sugarcane)	II	III	I	II	II	III	III	III	Numerous barriers to upland field use because of severe soil erodibility, poor nutrient levels, etc. Strongly acid.	○		△	△	○	○	○
Ysd					U (Pineapple, Sugarcane)	II	III	I	II	I	II	III	III	Numerous barriers to upland field use because of severe soil erodibility, poor nutrient levels, etc. Moderately acid.	○		△		○	○	○
Its/ Trm	Red soil	Lime-stone terrace	deposit on limestone		U (Sugarcane, Tobacco, Pumpkin)	I	I	I	III	III	II	I	I	Suitable for upland field use if improvement of water-holding capacity by deep plowing and soil dressing are performed. Irrigation required in dry years. Neutral.			○	○	△		
Mbn					U (Sugarcane)	I	I	I	IV	III	II	I	I	Suitable for upland field use if improvement of water-holding capacity by deep plowing, soil dressing and gravel removal are performed. Irrigation required in dry years. Neutral.			◎	○	△		
Inm	Terrest-rial Rego-sol	Hill	Marl		U (Sugarcane, Pumpkin, String bean)	II	II	II	I	I	III	I	I	Suitable for upland field use if improvement of ease of plowing is performed. Care is needed to prevent wetness damage because of high water-holding capacity and poor permeability. Slightly alkaline.	△	△			○		
Iju					U (Sugarcane)	II	II	I	II	III	III	I	I	Suitable for upland field use if improvement of ease of plowing is performed. Improvement of water-holding capacity by deep plowing is required. Moderately alkaline.	△		△	○	○		
Onh	Brown Low-land soil	Recent alluvial plain	Calcar-eous deposit		U (Sugarcane)	I	I	III	I	I	III	I	I	Suitable for upland field use if improvement of ease of plowing is performed. Drainage is required. Slightly alkaline.		○			○		
Izm			Non-cal-careous deposit		U (Sugarcane)	I	I	II	I	I	III	II	III	Potential for upland field use, if supply of lime, organic matter and nutrients is performed. Moderately acid.		△			○	○	○

*1) Climate type; Cf: Humid temperature climate. Soil moisture regime; U2: Perudic (<30 dry days), U1: Udic (30-90 dry days), Us: Ustic (90-180 dry days).

*2) Class; I : Land has almost no limitation or hazard, II : Land has some limitations or hazards and some improvement practices are required, III: Land has many limitations or hazards and fairly intensive improvement practices are required, IV: Land has greater natural limitations or hazards than those in class IIIbut can be cultivated for some crops under careful management.

*3) Necessity of soil management measures; ◎: Essential, ○: Major, △: Some.

In flat lower terraces, if soil improvement by the application of organic matter, lime, and nutrient supply are performed while taking soil erosion preventive measures, use as upland fields is also possible (Table 2).

The land grouping of Dark Red soils which develop on coral limestone terraces is found in the flat lands, and is suitable for upland field use, because it is at low risk of soil erosion, has a comparatively large nutrient holding capacity, and is slightly acid to neutral (Table 2). In this land grouping, corn, peanut, sweet potato, etc. are actually grown while coconut and cashew in areas with a dry season are grown in orchards. Although this land grouping is used for sugarcane cultivation in the Amami and Ryukyu Islands, it is seldom used for this purpose in the Philippine Islands.

Since the bedrock is often close to the surface, the effective depth of the soil is shallow and water retentivity is also comparatively low in this land grouping, so it tends to experience drought. Moreover, in this land grouping, lack of potassium is often accompanied by lack of phosphorus. Therefore, for upland field use of this land grouping, the supply of nutrients such as phosphorus, potassium etc., and irrigation in the dry season are required.

The land grouping of Vertisols and different lowland soils are distributed in alluvial lowlands (Table 3). Vertisols have strong stickiness and bad soil tilth, and become waterlogged in the rainy season and dry out easily in the dry season. However, they are commonly used as upland fields because they have comparatively good fertility and nutrient status. In the Philippines, since Vertisols are found in the lowlands, they grow paddy rice on them in the rainy season and upland crops such as tobacco in the dry season. For upland field use of Vertisols, improvements to soil tilth, irrigation in the dry season, and drainage in the rainy season are required.

The lowland soils of alluvial lowlands are usually suitable for use as upland fields, since they are in the flat lands, and there is also comparatively low risk of soil erosion (Table 3). Lowland soils can be used for the multiple cropping of paddy rice and field crops, depending on the moisture conditions, because they have comparatively high soil fertility together with a low risk of soil erosion. If intensive utilization is made of lowland soils by multiple cropping, high land productivity can be achieved. Higher productivity can be gained by irrigating in the dry season.

Based on the soil productive capability classification in upland field use of the site representing the main land grouping of Okinawa (Okinawa Prefecture, 1979), the guidelines for land use and soil management measures for upland field use are shown in Table 4.

The land grouping of Red-Yellow soils suffers many problems in upland field use, since it also has strong acidity, low water resistance, and poor nutrient levels. In practice, in the case of Okinawa, this land grouping is used for upland fields but can be improved only at great expense. The main crops in the land grouping are pineapple and sugarcane in the Amami and Ryukyu Islands. However, in this land grouping, soil erosion remains a major problem; there is an urgent need for further erosion-preventive measures.

The land grouping of Dark Red soils on coral limestone terraces is suitable for upland field use, since it has a comparatively low risk of soil erosion combined with relatively high fertility. Sugarcane, tobacco, Japanese pumpkins, etc. are currently grown in this land grouping. However, since this land grouping often has shallow effective depth of soil and low water retentivity, and dries out easily, improvement of water retentivity by deep tillage or soil dressing and irrigation are required for their effective use. Soil dressing with weathered materials from "Kucha" marl, which has high water retentivity, is actually performed in the south of the main Okinawa island.

In areas with a dry season in Okinawa, the calcaric Terrestrial Regosol becomes a Vertisol. The Terrestrial Regosols are slightly alkaline, suitable for upland field use, and are used for cultivation of sugarcane, Japanese pumpkins, string beans, etc. However, it has strong stickiness, and improvement of the soil tilth by addition of organic matter or soil dressing is required for Terrestrial Regosols. Moreover, it is necessary to increase water retentivity by deep tillage in places where the effective depth of the soil is shallow.

The land grouping of Brown Lowland soils and Gray Lowland soils of alluvial lowlands is suitable for upland field use and is extensively used for the cultivation of sugarcane. However, drainage is required for upland field use of Gray Lowland soils. Gray Lowland soils and Gley Lowland soils are mainly used as paddy fields.

5. Conclusions

The soils in the tropical and subtropical islands are very diverse, not only because of their complicated

geology and topography but also due to variable weather conditions. The different soils and weather conditions lead to a diversity of cropping systems.

Upland crop production can be promoted in the tropical and subtropical islands by intensive utilization of soils that have relatively low erodibility and high nutrient status, such as Dark Red soils (Luvisols or Alfisols), Vertisols and related soils, and Lowland soils. However, irrigation is necessary for dry-season cropping. Red-Yellow soils (Alisols, Acrisols, or Ultisols), which have high erodibility and low nutrient status, are better used for orchard vegetative cultivation. Huge costs are required to convert these soils to suit them for ordinary upland cultivation.

Soil and climatic resources are important considerations when selecting a cropping system or land use to match a certain combination of soil type and climate.

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