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Paddy Soils in Tropical Asia

Part 1. Description of Fertility Characteristics

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Tropical Asia is noted as the region where more than 1/4 of the world's population today is concentrated on only 1/16 of the world's land surface. This extraordinarily high population density has been and is being supported by rice cultivation.

Paddy soils are found mainly on alluvial lands such as deltas and flood plains of big rivers, coastal plains, fans and lower terraces. Their distribution among different countries in tropical Asia is shown in Table 1.[1] Annually a total of some 82 million ha of paddy land is cultivated to rice in this region of the world. As the double cropped rice area, if any, is very small, the above figure can be regarded as the total extent of paddy soils in tropical Asia.

These paddy soils are mostly alluvial soils and low humic gley soils (or Entisols and Inceptisols). Grumusols (or Vertisols), reddish-brown earths (or Alfisols), red-yellow podzolic soils (or Ultisols) and latosols (or Oxisols) are also utilized, but to a limited extent.

The fertility status of these different soils is naturally different. Even within one group of soils, in particular within alluvial soils, it differs markedly depending on the nature and the degree of weathering of the parent sediments. Naturally, these differences in fertility result in the differences in productivity of rice. This is particularly true for the extensive agriculture as practised in tropical Asia today.

In view of the importance of soil factor in the rice production in tropical Asia, a comparative study of paddy soils of the countries in the region has been carried out since 1963. The countries so far covered are India (eastern part), Bangladesh, Sri Lanka, part of Burma, Thailand, Cambodia, Malaysia (West), Indonesia (Java), and the Philippines. Although a greater part of Burma, Laos, Viet-Nam, East Malaysia, and outer territories of Indonesia are yet to be covered, the results obtained in the past 10 years appear to be quite substantial to draw some generalizations about paddy soils in tropical Asia, especially with respect to their material feature and fertility status.

In this series of papers, chemical, mechanical as well as mineralogical data obtained for sample soils will be described and analyzed. In the first paper of the series the data routinely analyzed for characterization of soil fertility will be described.

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Samples and Methods

The number of samples collected from each country is as follows:

		Note
Bangladesh	53	Throughout the country
Burma	16	Part of Irrawaddi delta and Upper Burma
Cambodia	16	Mainly areas around Grand Lac
India	73	Eastern States, excluding Assam
Indonesia	44	Java alone
Malaysia	41	Throughout West Malaysia
Philippines	54	Luzon, Panay, Leyte, and Mindanao
Sri Lanka	33	Throughout the country
Thailand	80	Throughout the country
Total	410	

The procedure and intensity of sampling are not uniform and the number of samples taken is not in proportion to the extent of rice lands in each country. This is the greatest drawback of the present study. Many factors limited the sampling, among which the more important ones are:

1) Availability of previous data on the distribution of different kinds of paddy soils. Number and kind of samples to be taken in each area and approximate sampling sites were determined after consulting with the local soils specialists. Quantity and quality of available data, however, varied greatly from one country to another, and even from one region to another within one country. For instance, in Thailand and Bangladesh FAO soil survey projects were in progress at the time of our sampling, and we were greatly assisted by the FAO and local soil survey specialists during the survey and sampling. But even within Thailand, not much data were available for the Upper Central Plain and we had to collect samples based on the extent of rice land, as read in the topomaps, and physiography, as observed in the field. Naturally the samples thus collected may not be necessarily representative.

2) Accessibility to the site. To save time and at times for reasons of personal security we had to confine our sampling to the areas of good access. This usually means the areas along the better-maintained roads.

In spite of these restrictions, the samples from all countries except Burma could be regarded as reasonably representative of the respective country, or at least the major rice growing region. Even so, as mentioned above the disparity in the number of samples from different countries still persist. The Burmese samples were collected only to get a preliminary idea on their nature on short trips designed for other purposes. We do hope to have another opportunity to collect samples more systematically from the entire country.

Methods of laboratory analyses are described elsewhere.[2] The accuracy and precision of the analyses were controlled by inclusion of a standard sample in each lot of samples analyzed.

Results and Discussions

Analytical data for the surface soil samples are presented and briefly discussed item-wise. Histograms are prepared by setting 10 classes; the class limits are set so as (1) to give the same interval to each class, except the two outermost classes, and (2) to put a small percentage (not more than 10%) of the entire samples into the uppermost class. For each item a histogram and/or a table showing country means and other statistics are given. For the purpose of comparison, data of Japanese and Mediterranean (Italy, Spain, and Portugal) paddy soils are also cited in the table. These samples were collected and analyzed by us and could be regarded as representative of the respective regions.

Table 1 Areas of Rice Cultivation in Tropical Asian Countries in 1971

	×1,000 ha		×1,000 ha
Bangladesh	9,776	Nepal	1,202
Brunei	4	Pakistan	1,456
Burma	4,764	Philippines	3,246
India	37,334	Sri Lanka	590
Indonesia	8,324	Thailand	6,900
Khmer (Cambodia)	1,880	Viet-Nam, North	2,400
Laos	665	Viet-Nam, South	2,625
Malaysia, East	173		
Malaysia, West	532	Sum Total	81,871

(Source: FAO, *Production Yearbook*, 1972)

Table 2 Mean, Standard Deviation, Minimum and Maximum Values of pH by Countries

Country	No. of Samples	Mean	Standard Deviation	Minimum	Maximum
Tropical Asia	410	6.0	1.1	3.4	9.3
Bangladesh	53	6.1	1.0	4.3	8.3
Burma	16	6.4	1.3	4.8	8.5
Cambodia	16	5.2	0.8	4.1	7.1
India	73	7.0	1.1	5.0	9.3
Indonesia	44	6.6	0.9	5.1	8.6
W. Malaysia	41	4.7	0.5	3.4	6.1
Philippines	54	6.4	0.6	4.8	8.5
Sri Lanka	33	5.9	0.8	4.9	8.4
Thailand	80	5.2	0.6	3.9	7.5
Mediter. Countries	62	6.8	1.0	5.4	8.6
Japan	84	5.4	0.5	3.8	6.3

1. pH (cf., Fig. 1 and Table 2)

The single analytical item that is most frequently quoted is pH. As will be seen in a later paper, it has many co-varying characters, such as base status and clay mineralogy.

The overall mean for the 410 samples is 6.0, but the mode is 4 that corresponds to pH 5.0∼5.5; the distribution is slightly positively skewed. Country-wise, West Malaysian paddy soils have the lowest mean value of 4.7, which is followed by Cambodia and Thailand's 5.2. The acid nature of Malayan paddy soils has been observed also by other researchers.[3] It is explained partly by intense leaching under the more uniformly humid climate and partly by frequent occurrence of paddy soils reclaimed from peaty swamps, having a high amount of unsaturated organic matter. The low pH of Cambodian soils is mainly due to abundance of sandy, acidic parent materials that have undergone severe weathering and leaching. The same applies to the soils of Northeast Thailand (Khorat Plateau). Another cause of the acidity of Thai paddy soils is the wide distribution of acid sulfate soils and the related acid soils in the Bangkok Plain.

The rest of the countries have high mean pH values nearly equal to or higher than 6.0, which is much higher than the mean pH value of 5.4 for Japanese paddy soils. Concentration of rainfall in half a year, resulting in a large runoff relative to percolation, and alternation of rainy and dry seasons are the factors counted for explaining the difference in the mean pH values between Japan and Sri Lanka, for example, which has an even greater annual precipitation than Japan.

The number of soils having pH values above 7 in each country is as follows:

Bangladesh	10	Malaysia	0
Burma	7	Philippines	4
Cambodia	1	Sri Lanka	4
India	30	Thailand	2
Indonesia	12		

The occurrence of the high pH soils is associated with the climate and/or parent material. Climatic influence is obvious from the fact that all 4 samples from Sri Lanka occur in the Dry Zone, all 12 soils in Indonesia come from Central and East Java where the climate tends to be drier than in West Java, and all 7 Burmese soils are from Upper Burma that has a distinctly drier climate than Lower Burma.

The effect of parent material is best seen in Bangladesh, where climate is almost uniform throughout the country. All the high pH soils occur in the region covered by the recent Gangetic alluvia. The calcareous nature of the Gangetic alluvia can be traced back into North India. Local calcareous materials such as weathering products of limestones and basic igneous rocks can produce small patches of high pH soils typically grumusolic in nature (Cambodia and Thailand). Another source of high pH soils is deposits in depressions under the wet and dry climate. Some of the high pH soils from India and the Philippines fall into this category.

Among the high pH soils from India there are two soils having pH values above 9. Both of these alkaline soils have high (more than 15%) exchangeable sodium.

Soils with exceptionally low pH, below 4.5, are also present, 3 from Cambodia, 15 from Malaysia, and 5 from Thailand. Many of these are peaty and/or swampy with sediments of brackish environment. Among the samples collected 6 are acid sulfate soils, all of which have without exception pH values below 4.5. Of these two Malayan and one Thai soils have pH even below 4. During the period of waterlogging for rice cultivation soil pH tends to rise and therefore even these acid sulfate soils are usually tolerated by rice plant.

2. Total Organic Carbon (T.C.) (cf. Fig. 2 and Table 3)

The histogram is strongly positively skewed. More than 55% of the total samples fall into classes 2 and 3, corresponding to 0.5~1.5% organic carbon. The overall mean is 1.4%, which is much lower than those of the middle latitude countries. The most plausible explanation for this is a high annual temperature and, accordingly, a high turn-over rate of organic residues.

West Malaysia has an exceptionally high mean T.C. value. Of the 11 samples falling into class 10 of the histogram, 8 come from Malaysia. These high T.C. samples of Malaysia are from swampy lowlands with peaty organic matter, which has been referred to in relation to pH. Even after excluding such swampy soils, however, Malayan paddy soils have the

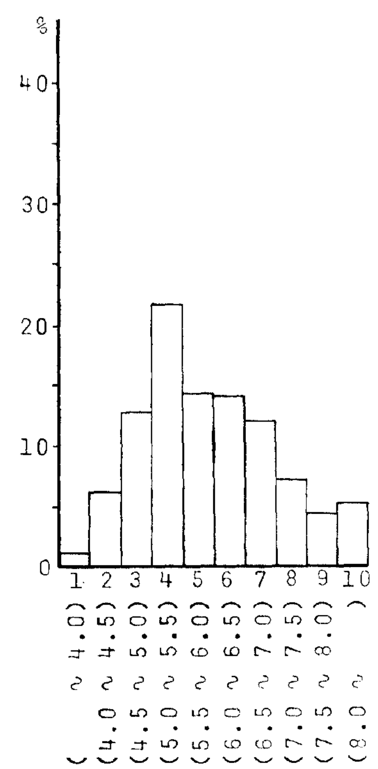

Fig. 1 Histogram for pH of Paddy Soils in Tropical Asia

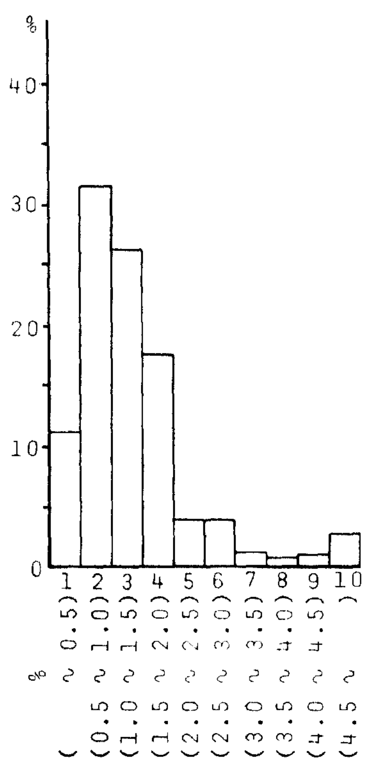

Fig. 2 Histogram for Total Organic Carbon Content of Paddy Soils in Tropical Asia

highest mean T.C. content of 2.0%. Soils from the Philippines, Sri Lanka and Indonesia form the second group with respect to the mean T.C. content. Internal heterogeneity, however, can be noted for these countries; samples from Mindanao, Leyte, and southern Luzon in the Philippines, those from Wet and Intermediate Zones in Sri Lanka, and samples from West Java in Indonesia seem to have elevated the country means. The common climatic element for these regions and Malaysia is the total absence or the mildness of the dry period. Thus, relatively more humid climate contributes to accumulation of T.C. in paddy soils.

Table 3 Mean, Standard Deviation, Minimum and Maximum Values of Total Organic Carbon by Countries (in % of air-dry soil)

Country	No. of Samples	Mean	Standard Deviation	Minimum	Maximum
Tropical Asia	410	1.41	1.28	0.12	11.40
Bangladesh	53	1.18	0.83	0.47	6.00
Burma	16	1.21	0.50	0.37	2.32
Cambodia	16	1.09	0.77	0.24	2.88
India	73	0.85	0.37	0.28	1.90
Indonesia	44	1.39	0.76	0.50	5.60
W. Malaysia	41	3.36	2.53	0.60	11.40
Philippines	54	1.66	0.64	0.52	3.30
Sri Lanka	33	1.41	1.50	0.18	8.49
Thailand	80	1.05	0.67	0.12	2.95
Mediter. Countries	62	1.82	1.45	0.35	8.60
Japan	84	3.33	2.02	1.00	11.36

Table 4 Mean, Standard Deviation, Minimum and Maximum Values of Total Nitrogen by Countries (in % of air-dry soil)

Country	No. of Samples	Mean	Standard Deviation	Minimum	Maximum
Tropical Asia	410	0.13	0.11	0.02	0.92
Bangladesh	53	0.13	0.07	0.05	0.52
Burma	16	0.10	0.04	0.04	0.18
Cambodia	16	0.10	0.07	0.03	0.29
India	73	0.08	0.03	0.02	0.20
Indonesia	44	0.12	0.08	0.05	0.59
W. Malaysia	41	0.28	0.21	0.05	0.92
Philippines	54	0.15	0.07	0.06	0.35
Sri Lanka	33	0.13	0.11	0.03	0.64
Thailand	80	0.09	0.06	0.02	0.27
Mediter. Countries	62	0.16	0.09	0.05	0.62
Japan	84	0.29	0.15	0.09	0.91

The lowest mean T.C. content is seen for Indian paddy soils, for which the coefficient of variation is also the lowest. In accordance with what has been stated above, the regional climate characterized by very high temperature at some time of the year and relatively low annual precipitation, appears to be the most contributory factor to the low T.C. level. Even the maximum figure is only less than 2% for India. Cambodian and Thai paddy soils have the second lowest mean values.

The maximum T.C. figures among Sri Lanka and Bangladesh soils are the data for swampy soils, whereas that among Indonesian soils is the datum for an ando soil that is of volcanic ash origin. The high organic carbon content of ando soils is an already established fact in Japan. As the allophanic nature of clay minerals of the ando soil of Indonesia has also been confirmed by us[4], we can assume the same mechanism of organic matter accumulation to apply to the Indonesian soil as proposed for Japanese ando soils.

The minimum figure for Thailand is the overall minimum and it is possessed by a sample from the Khorat Plateau.

3. Total Nitrogen (T.N.) (cf. Fig. 3 and Table 4)

The histogram shows a remarkable similarity to that of T.C. An even higher concentration of samples (ca. 65%) is seen in the classes 2 and 3, which correspond to T.N. content of 0.05 to 0.15%, and this is compensated by lesser frequencies in the higher T.N. classes. This fact may be interpreted as that the accumulation of organic matter often

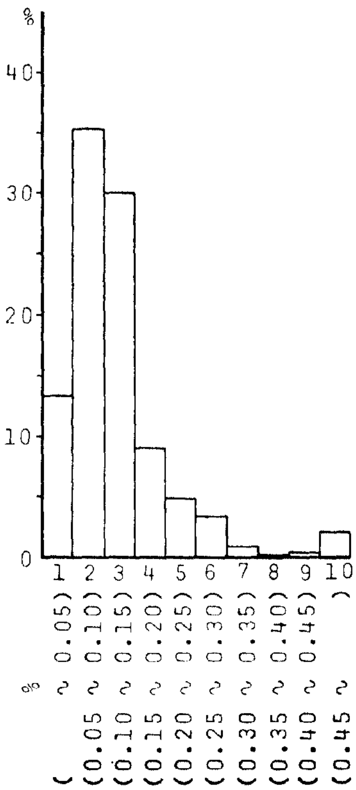

Fig. 3 Histogram for Total Nitrogen Content of Paddy Soils in Tropical Asia

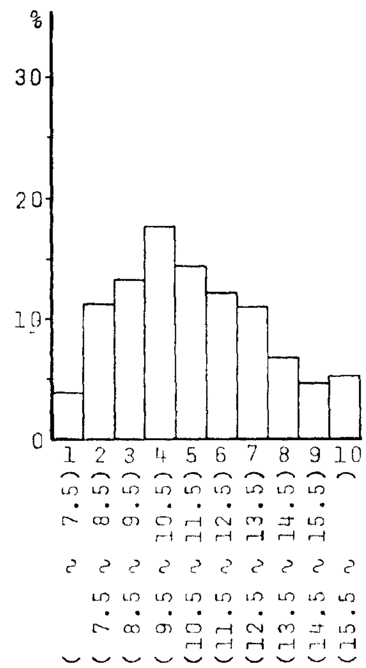

Fig. 4 Histogram for Carbon/Nitrogen Ratio of Paddy Soils in Tropical Asia

takes place in the form of less decomposed (or less humified) organic debris having a high C/N ratio.

Again Indian soils contain the least amount of nitrogen, which is almost 1/4 of the Japanese mean value. Soils from Cambodia and Thailand have means less than 0.1%. Burmese soils also have a low mean. On the contrary, Malayan soils have again an exceptionally high mean value.

In common to both T.C. and T.N., climate and local relief condition appear to be the most contributory to their accumulation. Texture may also have some effect. Correlation and regression analyses among these factors and organic matter will be done in a paper to follow.

4. Carbon/Nitrogen Ratio (C/N Ratio) (cf. Fig. 4 and Table 5)

As seen from the general parallelism between T.C. and T.N., C/N ratio fluctuates in a narrow range. Mean values of 8.7 and 12.6 for Bangladesh and Indonesian soils, respectively, represent the lower and upper extremes, and all others fall between 10 and 12. The overall mean is 11.2, which is comparable to the Japanese and Mediterranean means.

From this fact we may be able to conclude that no significant difference is found in the nature of soil organic matter between tropical and temperate paddy soils.

5. Ammoniacal Nitrogen (NH_4-N) (cf. Fig. 5 and Table 6 & 7)

The overall mean of ammoniacal nitrogen mineralized during reductive incubation period over 2 weeks is 8.5 mg/100 g soil, and the mean percentage ammonification is 6.8%. The variance of the data of NH_4-N production is very large and sample values range from 0.3 mg to 63 mg/100 g soil.

Characteristically low values of ammoniacal nitrogen released and percentage am-

Table 5 Mean, Standard Deviation, Minimum and Maximum Values of Carbon/Nitrogen Ratio by Countries

Country	No. of Samples	Mean	Standard Deviation	Minimum	Maximum
Tropical Asia	410	11.2	2.7	4.8	25.8
Bangladesh	53	8.7	1.1	7.1	12.4
Burma	16	11.5	1.5	8.6	13.4
Cambodia	16	10.7	1.8	7.7	13.7
India	73	11.7	2.5	4.8	18.4
Indonesia	44	12.6	3.5	8.3	25.8
W. Malaysia	41	11.8	2.3	9.2	19.8
Philippines	54	11.7	2.6	7.7	19.0
Sri Lanka	33	10.5	2.2	6.4	15.6
Thailand	80	11.3	2.9	6.0	22.2
Mediter. Countries	62	10.6	2.5	7.0	25.1
Japan	84	11.6	3.0	3.6	23.2

monification are seen for Indian and Burmese soils. The sample values of NH_4-N are confined to the first 3 classes in case of both Burmese and Indian soils. The low percentage ammonification may be due to a high resistance to microbial decomposition of the small reserve of organic matter in these soils.

A high mean NH_4-N production for Malayan soils is explained by the high mean T.N.

Table 6 Mean, Standard Deviation, Minimum and Maximum Values of Ammoniacal Nitrogen Production by Countries (in mg NH_4-N/100 g air-dry soil)

Country	No. of Samples	Mean	Standard Deviation	Minimum	Maximum
Tropical Asia	410	8.5	9.3	0.3	63.0
Bangladesh	53	6.1	4.8	1.6	31.8
Burma	16	2.0	1.6	0.4	6.0
Cambodia	16	4.0	2.2	0.5	7.8
India	73	2.7	1.4	0.5	7.3
Indonesia	44	14.1	8.7	3.6	36.6
W. Malaysia	41	14.9	9.9	3.8	40.3
Philippines	54	17.2	15.7	3.3	63.0
Sri Lanka	33	8.4	6.2	1.1	21.9
Thailand	80	5.2	3.2	0.3	16.4
Mediter. Countries	62	7.6	4.0	1.1	23.6
Japan	84	17.5	7.1	0.6	37.0

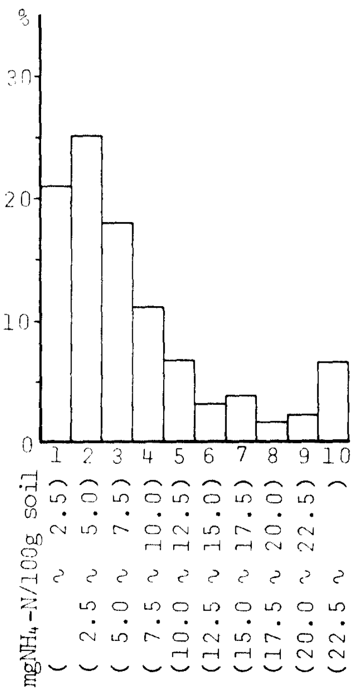

Fig. 5 Histogram for Ammoniacal Nitrogen Production of Paddy Soils in Tropical Asia

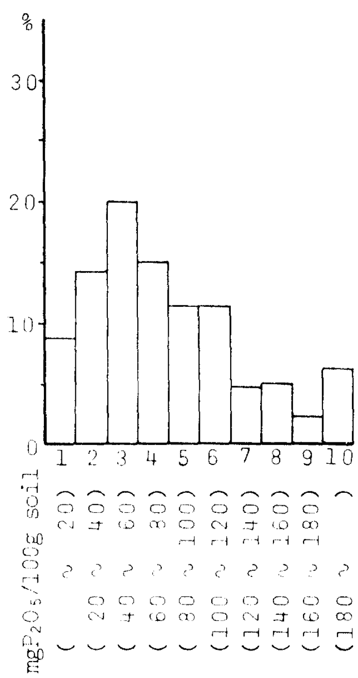

Fig. 6 Histogram for Total Phosphorus Content of Paddy Soils in Tropical Asia

content. The value of percentage ammonification is just normal for Malayan soils. But the high mean values of ammoniacal nitrogen for Indonesian and Philippine soils seem mainly due to high percentages of ammonification, 12 and 11% in average, respectively. Reasons for enhanced ammonification could not be readily given, but biological activity as controlled by base and other nutrient status should certainly have some relevance. In Indonesian and Philippine soils these factors may be working favorably

Extraordinarily high ammoniacal nitrogen production, say more than 25 mg/100 g soil, occur in the samples that were swampy or continuously wet in the field condition. The drastic change of the equilibrium condition might have caused instability of organic residues that had been accumulated in the swampy condition.

6. Total Phosphorus (T.P.) (cf. Fig. 6 and Table 8)

As phosphorus is readily bound by such soil constituents as iron, aluminum and calcium to form insoluble phosphate compounds, the level of T.P. can be modified rather easily by fertilizer applications. This effect can be seen in the case of Japanese paddy soils, whose 220 mg P_2O_5/100 g soil is presumably a result of fertilization. In comparison with this value the mean T.P. levels of tropical Asian paddy soils are low, indicating little human interference. The overall mean is 84 mg with a considerable variance. A high mean T.P. level over 100 mg is seen for Indonesian and Philippine soils, whereas a very low level prevails in Cambodian and Thai soils so that the means are only slightly more than 40 mg.

The number of samples in each country falling into the class 10 of the histogram that corresponds to more than 180 mg T.P./100 g soil, is listed below:

Table 7 Mean, Standard Deviation, Minimum and Maximum Values of Percentage Ammonification by Countries (in % of total nitrogen)

Country	No. of Samples	Mean	Standard Deviation	Minimum	Maximum
Tropical Asia	410	6.8	4.7	0.3	26.5
Bangladesh	53	4.5	1.9	1.6	10.8
Burma	16	1.8	1.2	0.3	5.0
Cambodia	16	5.1	2.9	0.7	10.0
India	73	3.9	2.2	1.0	14.8
Indonesia	44	12.4	5.0	4.4	25.4
W. Malaysia	41	6.3	3.6	1.5	14.7
Philippines	54	10.8	6.0	2.8	26.5
Sri Lanka	33	7.0	3.6	1.8	15.7
Thailand	80	6.6	3.6	0.8	18.3
Mediter. Countries	62	4.9	1.9	0.7	9.0
Japan	84	6.5	2.3	0.7	11.8

Table 8 Mean, Standard Deviation, Minimum and Maximum Values of Total Phosphorus by Countries (in mg P_2O_5/100 g air-dry soil)

Country	No. of Samples	Mean	Standard Deviation	Minimum	Maximum
Tropical Asia	410	83.7	66.8	1.0	553.0
Bangladesh	53	84.1	33.4	33.0	160.0
Burma	16	74.4	70.8	9.0	284.0
Cambodia	16	44.3	38.6	5.0	131.0
India	73	92.0	64.5	24.0	475.0
Indonesia	44	133.7	115.6	16.0	553.0
W. Malaysia	41	80.3	42.8	5.0	206.0
Philippines	54	113.6	60.2	23.0	249.0
Sri Lanka	33	72.5	47.1	13.0	174.0
Thailand	80	44.2	42.3	1.0	237.0
Mediter. Countries	62	103.8	46.3	14.0	253.0
Japan	84	220.4	126.9	86.0	861.3

Bangladesh	0	Malaysia	1
Burma	1	Philippines	8
Cambodia	0	Sri Lanka	0
India	4	Thailand	1
Indonesia	10		

The overall maximum T.P. of 553 mg is contained in an ando soil from Indonesia. From our experience with Japanese ando soils, it may be inferred that greater part of the phosphorus would exist in organic forms. Seven out of 10 high T.P. soils from Indonesia are latosols of Indonesian classification, which would correspond to Oxic Dystropept or Oxic Eutropept of the U.S. soil classification system. These latosols are characterized by relatively low available phosphorus in spite of their high T.P. level. As will be stated below this is a reason of low mean available phosphorus content of Indonesian paddy soils. The high phosphorus contents of the Philippine soils seem to be inherited from the parent materials of volcanic origin. Some of the swamp soils are rich in T.P., as seen in the examples from Malaysia and Thailand.

The number of soils containing less than 20 mg T.P. in each country is as follows:

Bangladesh	0	Malaysia	2
Burma	2	Philippines	0
Cambodia	5	Sri Lanka	1
India	0	Thailand	25
Indonesia	1		

These soils are generally sandy in texture, and mostly occur in higher terraces and plateaus bearing laterites or lateritic concretions. The majority of low T.P. Thai samples are from the Khorat Plateau region and are the soils derived from weathered Mesozoic sandstones. The 5 Cambodian samples are also derived from similar geologic formations. As the Japanese experience tells us that T.P. levels below 40 mg/100 g soil are critical for a normal rice growth, these low T.P. soils in tropical Asia would hardly escape from serious phosphorus deficiency.

7. Available Phosphorus (A.P.)

7–a) A.P. by Bray-Kurz No. 2 method. (Bray-P) (cf., Fig. 7 and Table 9)

As seen in the histogram the distribution of Bray-P is strongly positively skewed. More than 50% of the entire samples have less than 1.5 mg P_2O_5/100 g soil. The overall mean is only 3.8 mg, which is much less than the means for Japanese and Mediterranean soils.

The mean for Burmese samples is very high, containing a little more than 10 mg. But one of the Burmese samples has an exceptionally high Bray-P, 124.5 mg, and if this one is excluded the mean is drastically lowered to 2.7 mg. In case of Indian samples, the mean is kept relatively high at 5.2 mg even after excluding 2 samples that have more than 100 mg

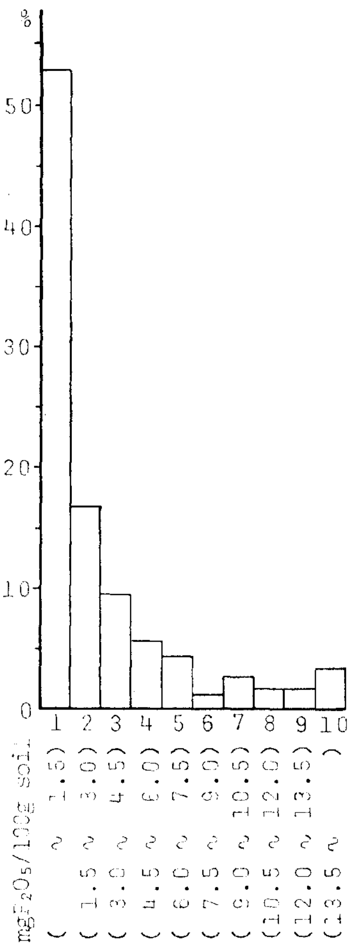

Fig. 7 Histogram for Available Phosphorus (Bray-P) Content of Paddy Soils in Tropical Asia

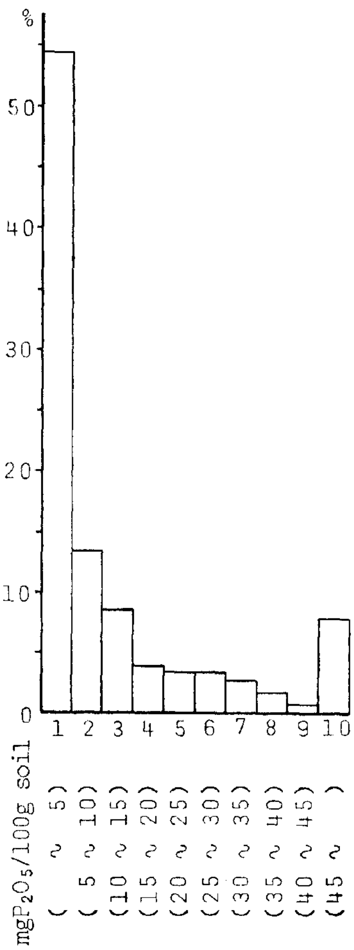

Fig. 8 Histogram for Available Phosphorus (HCl-P) Content of Paddy Soils in Tropical Asia

Bray-P. Reasons for these high Bray-P contents are not known.

The low means for Cambodia, Thailand and Sri Lanka suggest general paucity of available phosphorus in paddy soils of these countries. Indonesian soils are not quite rich either, irrespective of their relatively high total phosphorus content.

7-b) A.P. by 0.2 N HCl dissolution method (HCl-P) (cf. Fig. 8 and Table 10)

The level of HCl-P is always higher than that of Bray-P, because of the more drastic nature of the method. But general parallelism between the two is obvious.

The high Burmese and Indian means are lowered to 13.1 mg and 17.6 mg, respectively,

Table 9 Mean, Standard Deviation, Minimum and Maximum Values of Available Phosphorus (Bray-P) by Countries (in mg P_2O_5/100 g air-dry soil)

Country	No. of Samples	Mean	Standard Deviation	Minimum	Maximum
Tropical Asia	410	3.8	10.6	tr.	124.5
Bangladesh	53	3.8	3.1	0.3	12.3
Burma	16	10.3	30.6	0.5	124.5
Cambodia	16	0.6	1.1	0.1	3.9
India	73	8.1	18.7	0.2	121.3
Indonesia	44	2.4	2.8	0.1	14.1
W. Malaysia	41	3.7	4.2	0.3	20.0
Philippines	54	3.7	4.5	0.1	17.8
Sri Lanka	33	1.4	1.3	0.1	7.4
Thailand	80	1.4	3.2	tr.	21.2
Mediter. Countries	62	7.2	6.7	tr.	31.9
Japan	84	12.9	11.7	0.1	63.0

Table 10 Mean, Standard Deviation, Minimum and Maximum Values of Available Phosphorus (HCl-P) by Countries (in mg P_2O_5/100 g air-dry soil)

Country	No. of Samples	Mean	Standard Deviation	Minimum	Maximum
Tropical Asia	410	12.9	23.0	0.1	205.9
Bangladesh	53	21.0	21.3	0.1	75.4
Burma	16	24.1	47.1	0.6	190.0
Cambodia	16	1.9	5.0	0.2	20.4
India	73	21.9	32.8	0.1	205.9
Indonesia	44	10.0	13.2	0.4	51.6
W. Malaysia	41	8.2	11.9	0.2	63.0
Philippines	54	13.4	17.6	0.5	83.7
Sri Lanka	33	9.0	23.3	0.2	135.0
Thailand	80	4.7	13.7	0.1	112.6
Mediter. Countries	62	—	—	—	—
Japan	84	46.5	34.7	0.1	166.0

after the exclusion of the exceptional cases. Soils from Cambodia and Thailand are still critically low in this form of available phosphorus. Malaysia, Sri Lanka and Indonesia soils are moderate, and Philippine and Bangladesh soils are good, though their HCl-P contents are still very low in comparison with that in Japanese soils.

8. Cation Exchange Capacity (CEC) (cf., Fig. 9 and Table 11)

CEC is one of the most important fertility characteristics and, like pH, has many co-varying characters, such as texture, base status and clay composition.

The histogram shows a positive skewness and the overall mean of 18.6 me/100 g soil is far from the mode, which corresponds to 5～10 me. CEC ranges from 0.6 me for a sandy Khorat Plateau soil in Thailand to 56 me for a grumusol in India.

High means and relatively low variances are seen for the samples from Indonesia and the Philippines. The soils of both the countries are generally rich in good-quality clays. Sri Lanka and Bangladesh soils have low mean CEC values. The mode of the Thai soils is 1, which corresponds to CEC values less than 5 me. Most soils falling into this class come from the Khorat Plateau. The maximum figures for most countries are obtained with grumusols or grumusolic alluvial soils.

In spite of the high organic matter content, both the mean and the maximum figures for Malayan soils are not remarkably high. The reason for this may be sought in the nature of the organic matter.

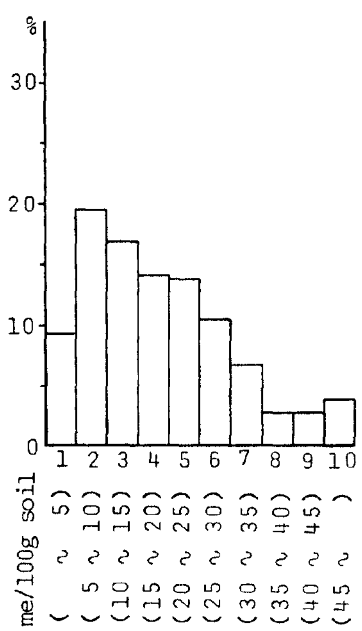

Fig. 9 Histogram for Cation Exchange Capacity of Paddy Soils in Tropical Asia

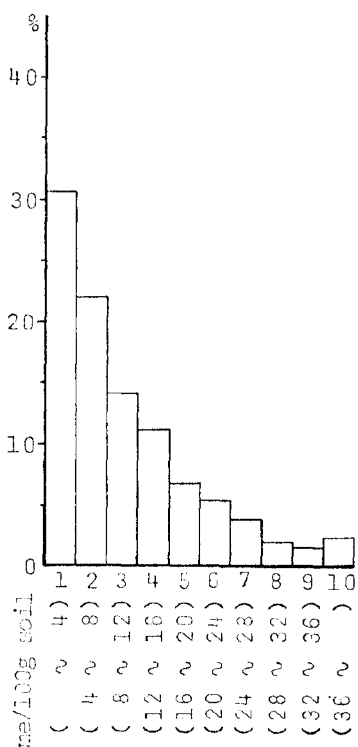

Fig. 10 Histogram for Exchangeable Calcium Content of Paddy Soils in Tropical Asia

Table 11 Mean, Standard Deviation, Minimum and Maximum Values of Cation Exchange Capacity by Countries (in me/100 g air-dry soil)

Country	No. of Samples	Mean	Standard Deviation	Minimum	Maximum
Tropical Asia	410	18.6	12.0	0.6	56.0
Bangladesh	53	12.9	7.0	3.6	32.5
Burma	16	18.6	9.1	5.6	33.4
Cambodia	16	14.6	10.4	2.1	34.8
India	73	22.0	13.7	1.7	56.0
Indonesia	44	26.1	12.6	3.0	55.4
W. Malaysia	41	15.9	8.6	2.9	33.2
Philippines	54	27.0	11.8	6.3	52.3
Sri Lanka	33	11.5	7.1	3.0	34.2
Thailand	80	14.4	10.5	0.6	54.3
Mediter. Countries	62	18.0	11.6	1.6	37.0
Japan	84	20.3	7.0	8.8	38.0

Table 12 Mean, Standard Deviation, Minimum and Maximum Values of Exchangeable Calcium by Countries (in me/100 g air-dry soil)

Country	No. of Samples	Mean	Standard Deviation	Minimum	Maximum
Tropical Asia	410	10.4	9.9	0.1	64.7
Bangladesh	53	7.8	7.8	0.2	33.1
Burma	16	10.1	10.6	1.5	38.7
Cambodia	16	5.4	3.6	0.7	12.5
India	73	15.0	10.9	0.2	38.6
Indonesia	44	17.8	14.2	1.2	64.7
W. Malaysia	41	3.9	3.4	0.1	12.3
Philippines	54	14.8	7.1	2.7	29.3
Sri Lanka	33	5.4	5.0	0.5	22.0
Thailand	80	7.2	7.5	0.2	43.8
Mediter. Countries	62	15.9	13.1	2.0	38.3
Japan	84	9.3	5.3	1.6	44.9

9. Exchangeable Calcium (Ex-Ca) (cf. Fig. 10 and Table 12)

Exchangeable calcium occupies the major portion of the total exchangeable cations. In our analysis part of free calcium carbonate present in some sample soils is measured together with exchangeable calcium and this explains why some of the maximum figures are even greater than the corresponding maximum CEC values.

Reflecting the acid nature, Malayan soils have the lowest mean Ex-Ca. Cambodia and Sri Lanka samples also show low means. Indonesia, India, and the Philippines have higher mean values, of which Philippine soils have the highest mode and the minimum variance.

Among the soils containing high Ex-Ca (including those having free carbonates) there are two broad groups. One is grumusols and the other is alluvial soils on recent calcareous alluvia. The latter is typically seen in the Gangetic alluvial region in North India and Bangladesh. Recent alluvia of the Solo in East Java are also calcareous. Grumusols (or regurs) occur widely in India, in Upper Burma, and in Central and East Java, and as patches in Thailand, Cambodia, Sri Lanka (Dry Zone), and the Philippines.

10. Exchangeable Magnesium (Ex-Mg) (cf. Fig. 11 and Table 13)

The overall mean Ex-Mg content is 5.5 me/100 g soil, which constitutes about 30% of the mean CEC. This computation is permissible because free Mg salts seldom occur, except for a few soils recently reclaimed from marine clays.

Soils containing relatively more Ex-Mg over Ex-Ca can be considered to have been derived from marine or brackish alluvia. Ex-Mg content greater than 5 me and Ex-Mg/Ex-Ca ratio greater than unity may be used for differentiating soils of marine or brackish alluvia origin. Acid sulfate soils, however, do not satisfy one or both of the above criteria.

Grumusols and related soils derived from basic igneous rocks contain a high amount of Ex-Mg, but in these soils Ex-Ca content is even higher.

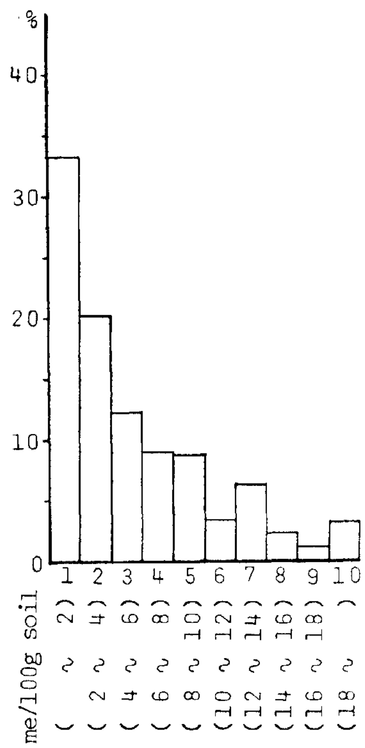

Fig. 11 Histogram for Exchangeable Magnesium Content of Paddy Soils in Tropical Asia

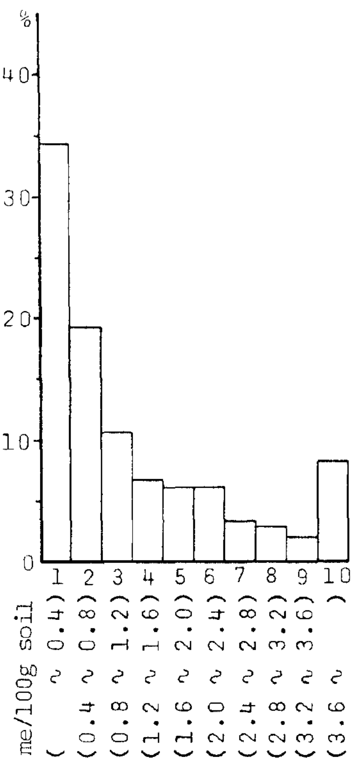

Fig. 12 Histogram for Exchangeable Sodium Content of Paddy Soils in Tropical Asia

Frequency of the two groups of soils stated above among the samples explains the mean values for different countries. Philippines, India and Indonesia have many samples of grumusolic nature. In case of Burma, deltaic soils are of marine clay origin and Upper Burma soils are grumusolic. Bangladesh, Cambodia and Sri Lanka samples have only a few of these soils. The Bangkok Plain soils have pushed up the mean for Thailand slightly.

The overall maximum figure is shown by a soil of marine clay origin in the Bangkok Plain of Thailand, which has about 10 me of water soluble magnesium salts.

11. Exchangeable Sodium (Ex-Na) (cf. Fig. 12 and Table 14)

Table 13 Mean, Standard Deviation, Minimum and Maximum Values of Exchangeable Magnesium by Countries (in me/100 g air-dry soil)

Country	No. of Samples	Mean	Standard Deviation	Minimum	Maximum
Tropical Asia	410	5.5	5.3	0.1	34.1
Bangladesh	53	2.7	2.4	0.1	9.6
Burma	16	7.7	6.1	0.7	20.8
Cambodia	16	3.2	3.5	0.1	12.0
India	73	6.5	5.1	0.3	24.4
Indonesia	44	6.3	3.9	1.1	15.5
W. Malaysia	41	5.2	6.4	0.4	28.7
Philippines	54	9.3	6.0	1.0	29.3
Sri Lanka	33	3.5	3.5	0.1	14.7
Thailand	80	4.3	5.5	0.1	34.1
Mediter. Countries	62	4.6	4.0	0.8	15.0
Japan	84	2.8	1.8	0.5	9.4

Table 14 Mean, Standard Deviation, Minimum and Maximum Values of Exchangeable Sodium by Countries (in me/100 g air-dry soil)

Country	No. of Samples	Mean	Standard Deviation	Minimum	Maximum
Tropical Asia	410	1.5	3.0	tr.	46.0
Bangladesh	53	0.9	1.2	0.1	5.3
Burma	16	0.6	0.8	0.1	3.5
Cambodia	16	0.3	0.3	0.1	0.9
India	73	2.4	2.0	0.1	8.3
Indonesia	44	1.5	1.5	0.2	6.3
W. Malaysia	41	1.5	4.1	0.1	26.0
Philippines	54	2.2	1.8	0.3	8.9
Sri Lanka	33	0.5	0.6	0.1	2.7
Thailand	80	1.4	5.3	tr.	46.0
Mediter. Countries	62	1.0	1.3	0.1	6.4
Japan	84	0.4	0.4	0.1	2.9

Sodium is one of the most mobile elements in the soil. Therefore, where climate is humid, sodium is leached out of all soils regardless of their physiographic position. This is the case for Japanese soils, whose mean Ex-Na content is only 0.4 me/100 g soil. But where climate is dry or alternately wet and dry, sodium tends to be accumulated in the lower physiographic position as a result of leachmg from the higher positions. Thus, paddy soils in lowlands are apt to be enriched with sodium in most part of tropical Asia.

Reflecting the climatic condition Indian soils have the highest mean Ex-Na content. The high mean value for the Philippines seems partly due to the nature of parent materials. The parent material feature seems to have played a role also in setting the lowest mean for Cambodian soils.

There are cases of abnormally high Ex-Na content. The maximum figures in Thailand and Malaysia are explained by the occurrence of free Na salts in the soils of recent marine clay origin, which contain also free Mg salts. Some of the soils from the Khorat Plateau region of Thailand are known to have a high content of sodium. This is explained by the occurrence of salt bed intercalated in the sandstone basement. Sodium chloride is supplied to the surface soil by capillary rise of ground water during the dry season.

When sodium is present in considerable amount as exchangeable cations, it tends to give a high pH as a result of hydrolysis. Besides the alkaline soils in India referred to earlier, there are soils having pH above 7 and high relative percentage of Ex-Na in spite of their unsaturated exchange complex.

One should note here that most of our samples were collected during the dry season when sodium content is at its maximum. At the onset of the rainy season, much of the sodium

Table 15 Mean, Standard Deviation, Minimum and Maximum Values of Exchangeable Potassium by Countries (in me/100 g air-dry soil)

Country	No. of Samples	Mean	Standard Deviation	Minimum	Maximum
Tropical Asia	410	0.4	0.3	tr.	2.6
Bangladesh	53	0.3	0.2	tr.	0.8
Burma	16	0.4	0.2	0.1	0.7
Cambodia	16	0.2	0.2	tr.	0.8
India	73	0.5	0.4	0.1	2.3
Indonesia	44	0.4	0.3	0.1	1.2
W. Malaysia	41	0.4	0.4	0.1	1.8
Philippines	54	0.5	0.3	0.1	1.7
Sri Lanka	33	0.2	0.2	tr.	0.7
Thailand	80	0.3	0.4	tr.	2.6
Mediter. Countries	62	0.6	0.7	0.1	2.8
Japan	84	0.4	0.3	tr.	1.4

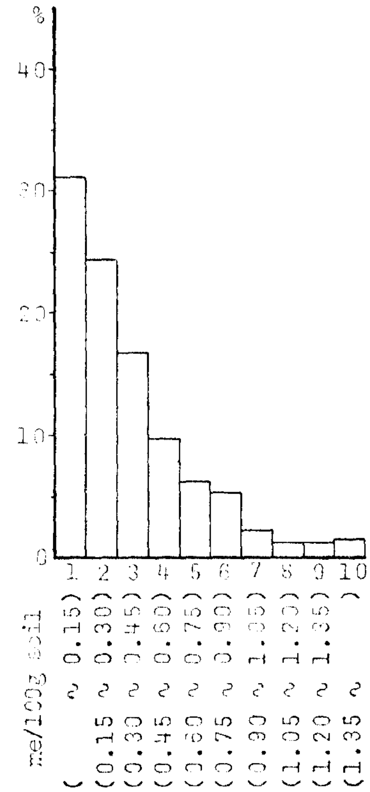

Fig. 13 Histogram for Exchangeable Potassium Content of Paddy Soils in Tropical Asia

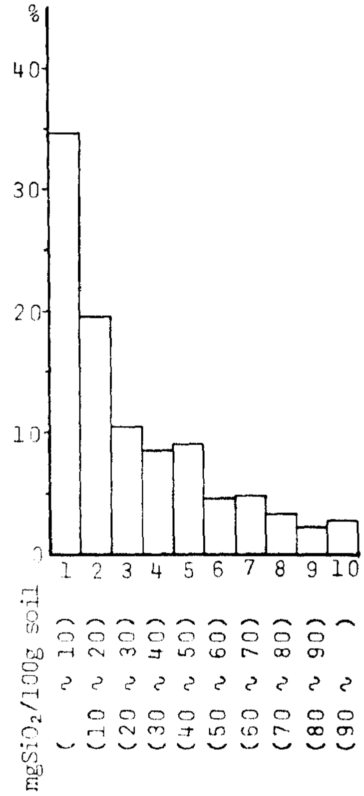

Fig. 14 Histogram for Available Silica Content of Paddy Soils in Tropical Asia

ions would be leached and the Ex-Na status during the rice growing season could be different from what we have reported on the samples.

12. Exchangeable Potassium (Ex-K) (cf. Fig. 13 and Table 15)

It is at once obvious from the table that Ex-K level is much lower than that of Ex-Na. This is partly due to relative stability of K-bearing minerals, such as orthoclase and mica, in the soil system as compared to Na-containing plagioclase. There may also be a mechanism operating in the soil to suppress potassium level in the soil solution, such as potassium fixation by 2 : 1 clays. Selective uptake of potassium by plants must also be counted.

If we disregard the difference in the general level, however, Ex-K shows behavior similar to that of Ex-Na. Again Indian soils have the highest mean Ex-K and Cambodian soils the lowest. The overall maximum content of Ex-K is seen in a Thai soil derived from marine clay, which has also the highest amounts of Mg and Na.

Some soils contain only trace of Ex-K. But even in such soils rice plants can take up potassium from irrigation water that usually contains 1 to 2 ppm or more as K. If we assume that the water requirement for a single crop of rice is 1,000 mm, only 1 ppm of an element in the irrigation water would supply about 10 kg of that element per hectare per crop. This much of supply through irrigation water would rarely make potassium a limiting factor to the crop growth.

13. Available Silica (cf. Fig. 14 and Table 16)

Silica is not thought to be essential to most agricultural crops, but for rice it is regarded as essential. Based on the pH 4 acetate buffer-soluble silica in the soil, requirement for silica-containing fertilizers is judged. The criterion adopted in Japan is as follows:

Response	Available SiO_2, mg/100 g soil
Always negative	>13.0
Positive or negative	10.5∼13.0
Always positive	<10.5

The same criterion may not be applicable to the tropical paddy soils, as the rate of silica release from soil minerals or weathering intensity seems to be higher in the tropics. The same reasoning could be applied to explaining the high overall mean of 27 mg, which is higher than the Japanese mean, which, in itself, is already high because of the wide distribution of volcanic ejecta.

Coefficients of variation (c. v.) are lower for the countries having high mean values, e.g., Indonesia and the Philippines. India and Burma have medium means and c.v. The other countries have relatively low means and high variance. This together with the histogram showing strong positive skewness suggests that many samples from these latter countries would have critically low silica contents.

By setting a threshold value for available silica tentatively at 5 mg/100 g soil, which is about one half of the Japanese value, the number of samples having available silica less

Table 16 Mean, Standard Deviation, Minimum and Maximum Values of Available Silica by Countries (in mg SiO_2/100 g air-dry soil)

Country	No. of Samples	Mean	Standard Deviation	Minimum	Maximum
Tropical Asia	410	27.0	25.5	0.1	119.6
Bangladesh	53	12.9	11.4	2.2	49.0
Burma	16	22.1	15.8	4.1	54.1
Cambodia	16	11.3	10.6	1.2	39.6
India	73	34.7	24.8	0.3	87.1
Indonesia	44	62.9	25.6	5.4	119.6
W. Malaysia	41	10.4	10.0	1.0	53.5
Philippines	54	45.4	23.9	6.7	111.7
Sri Lanka	33	21.6	20.4	1.9	81.3
Thailand	80	12.2	11.1	0.1	54.0
Mediter. Countries	62	23.9	17.8	4.3	82.7
Japan	84	19.5	21.9	3.5	114.4

than this value is listed below for each country:

Bangladesh	15	Malaysia	11
Burma	1	Philippines	0
Cambodia	6	Sri Lanka	5
India	6	Thailand	25
Indonesia	0		

These soils are almost without exception sandy in texture and low in pH. They occur most widely in the Khorat Plateau region of Thailand, and in the marginal plains and Pleistocene terraces (Madhpur and Barind tracts) of Bangladesh.

The soils with very high silica contents, more than 40 mg, are either those derived from recent volcanic ejecta in the Philippines and Indonesia or those of grumusolic nature occurring in the climatic regions with a distinct dry season. The soils of swampy lands have moderate amounts of available silica.

Summary

The results of laboratory studies conducted on 410 sample soils collected from different countries of tropical Asia have been described. The items taken up in this paper are those routinely analyzed for characterization of fertility status of paddy soils, such as pH, total carbon, total nitrogen, ammoniacal nitrogen, total and available phosphorus, cation exchange capacity, exchangeable cations, and available silica. A histogram and/or a table showing country means and other statistics were given for each item.

Many of these characters are correlated with each other and with material as well as climatic and local relief features. This aspect of the data will be dealt with in one of the papers to follow.

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