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A New Soil Material Classification for Tropical Asian Paddy Soils

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Studies on paddy soils of Tropical Asia [Kawaguchi and Kyuma 1977; Kyuma 1976; 1977; 1978] have yielded a large body of data on their chemical and physical properties. From these data, those on the contents of nine major elemental oxides and three textural separates were used to set up soil material classes, in the hope that such a classification would help in evaluating and characterizing the potential capability of Tropical Asian paddy soils [Kawaguchi and Kyuma 1975; 1976].

The soil material classification thus established was found useful for general capability evaluation. But, in a more recent study, it was found less useful for predicting the trace element status of the soils [Domingo and Kyuma 1983b]. Therefore, an attempt to set up a new soil material classification has been made based on a new set of data including those of trace elements.

Data and Methods Used

In the new classification of soil materials, the data used to represent material nature were the contents of both total macro and microelements and the mechanical compositions, which were obtained in the previous studies [Domingo and Kyuma 1983a; Kawaguchi and Kyuma 1977].

Correlation coefficients between all pairs of data were calculated to determine the highly correlated pairs of characters. Starting with a correlation matrix of 28 characters, a principal component analysis (PCA) was run to transform the original set of correlated variates into a new set of mutually uncorrelated variates in such a way that a few components would represent a large proportion of the total variance in the original data.

In the course of preliminary trials with PCA, several compound characters or principal components were found to be quite consistently extracted, and those variates which did not independently contribute to these components were successively eliminated. For example, clay was eliminated because both clay and sand contributed to one of the components and they were also mutually highly correlated. On the other hand, molybdenum was eliminated because it did not contribute to any one of these principal components. Finally, a set of 21 characters was used.

With the reduced correlation matrix of

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Table 1 Terminal Factor Loading Matrix for Six Factors after Varimax Rotation

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
Sand	−0.661	0.201	−0.243	−0.183	0.357	0.306
Fe_2O_3	0.835	0.202	0.135	−0.076	0.069	0.171
Al_2O_3	0.723	0.155	0.098	0.202	−0.123	−0.328
CaO	0.125	0.708	−0.178	−0.049	−0.065	0.125
MgO	0.370	0.501	0.341	0.302	−0.065	0.051
MnO_2	0.531	0.346	−0.098	−0.263	0.031	0.364
TiO_2	0.517	−0.119	0.055	−0.132	0.680	0.004
K_2O	−0.018	0.033	0.080	0.878	0.029	−0.098
P_2O_5	0.313	0.349	−0.194	−0.045	0.148	−0.147
B	−0.000	−0.099	0.408	0.033	−0.021	−0.154
Cr	0.213	−0.094	0.884	0.039	−0.003	0.124
Co	0.234	0.304	−0.003	−0.136	0.117	0.238
Cu	0.106	0.023	0.193	−0.175	0.231	0.423
Ni	0.170	0.093	0.851	0.133	−0.051	0.139
Rb	−0.035	−0.265	0.139	0.774	−0.200	−0.052
Na	−0.115	0.690	0.169	0.004	−0.100	0.021
Sr	0.126	0.828	−0.149	−0.144	−0.011	0.045
V	0.786	0.013	0.097	−0.284	0.150	−0.090
Zn	0.585	0.134	0.342	0.214	−0.180	0.066
Zr	−0.283	−0.069	−0.135	−0.039	0.776	0.197
S	0.063	−0.070	0.035	−0.011	−0.015	−0.580

21 characters, a final PCA was run to determine the number of factors to be considered. The largest six eigenvalues, which are larger than unity, and the cumulative percentages of the total variance are:

Eigenvalue	% of Total Variance	Cumulative % of Total Variance
4.793	22.8	22.8
3.442	16.4	39.2
2.328	11.1	50.3
1.923	9.2	59.5
1.316	6.3	65.8
1.120	5.3	71.1

Since these six principal components are of more or less compound nature, and together account for more than 70% of total variance, they were used in the next steps of factor analysis.

By using squared multiple correlation coefficients between a specific variable and the others in the set as the preliminary communality estimate, principal factoring with iterations was performed. The final factor loadings were obtained as shown in Table 1.

Results and Discussions

Table 1 indicates the correlations between the six factors and characters. Factor 1 is highly correlated with most of the elements forming stable oxides, total vanadium and zinc, and highly negatively correlated with sand. It is thus an indicator of the "clay-oxidate" nature of soil material. Factor 2 is related with characters associated with base status, including strontium, and is hence an indicator of the "basic" nature. The third factor is highly correlated with high nickel-chromium status, and is an indicator of the "mafic" nature. Factor 4 is highly correlated with potassium and rubidium, and is therefore an indicator of the "micaceous" nature. Factor 5 is highly correlated with zirconium and titanium and moderately with sand. This factor is an indicator of the "resistate" nature. The last factor represents the "organophilic" nature of soil, being highly correlated with total carbon and sulfur, although total carbon was not included in the final analysis.

As these six factors are mutually independent and represent different aspects of material characteristics, their scores were computed and used for material classification by means of numerical taxonomy.

The actual procedure of numerical taxonomy consists of the following steps: computation of the Euclidian distance as the similarity coefficient, clustering by the Ward method, and formulation of the dendrogram.

Fig. 1 shows a dendrogram thus obtained for 235 randomly selected samples. Seven classes, numbered I to VII, were formulated, and these covered a total of 234 samples. Class I consisted of 41 samples, II of 17, III of 47, IV of 56, V of 26, VI of 21, and VII of 26, leaving one sample unclassified.

The means and standard deviations of the six factor scores were calculated for each of the seven classes, as shown in Table 2.

To see the basis of differentiation of the classes, the patterns of the six mean scores are shown in Fig. 2. The characteristics of each group can be described with respect to each of the factor scores.

In the figure, the regular hexagons represent the zero mean average score. Points inside it indicate below average status, those outside, above average. It is evident from the figure that soil material class III has the poorest quality as shown by the low negative scores with respect to all the factors, fol-

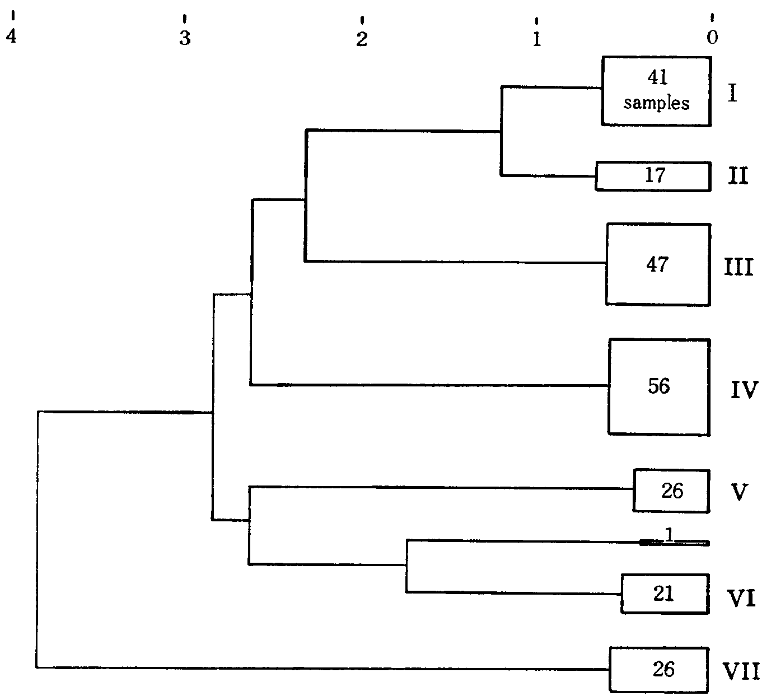

Fig. 1 Schematic Dendrogram Showing the Relation of the Seven Soil Material Classes

Table 2 Means and Standard Deviations of the Six Factors for the Seven Soil Material Classes

Class	Factor 1		Factor 2		Factor 3		Factor 4		Factor 5		Factor 6	
	Mean	S. D.	Mean	S. D.	Mean	S. D.	Mean	S. D.	Mean	S. D.	Mean	S. D.
I	0.277	0.475	−0.599	0.265	−0.091	0.503	0.201	0.702	−0.191	0.318	1.108	0.800
II	0.534	0.910	−0.609	0.404	0.628	0.915	−0.732	0.751	1.084	1.318	−0.991	0.489
III	−1.126	0.599	−0.657	0.315	−0.344	0.355	−0.578	0.630	−0.136	0.716	−0.245	0.523
IV	−0.091	0.684	−0.003	0.420	−0.321	0.393	1.209	0.564	−0.105	0.479	−0.291	0.342
V	0.186	0.760	1.861	0.854	−0.451	0.520	−0.401	0.671	−0.128	0.995	0.081	0.622
VI	1.685	0.826	0.027	0.582	−0.773	0.487	−1.069	0.305	−0.162	0.737	−0.390	0.425
VII	0.035	0.527	0.357	0.481	2.118	1.102	0.136	0.484	−0.242	0.214	−0.250	0.508

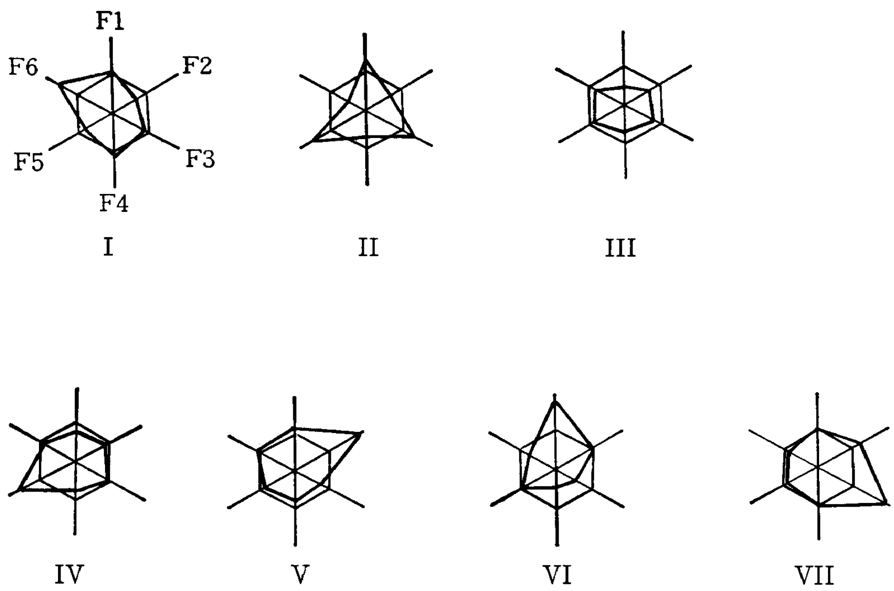

Fig. 2 Patterns of the Mean Factor Scores (FS) for the Seven Soil Material Classes

lowed by I, which has a highly organophilic nature. In contrast, class VII has better status, with above average mean scores with respect to factors 1, 2, 3, and 4. Classes V and VI are related to basic volcanic materials and show high scores in factors 2 and 1, respectively. Classes II and IV are judged to be intermediate in soil material quality. Class II has above average mean scores with respect to factors 1, 3, and 5, while class IV has prominently micaceous nature with a high mean score for factor 4.

Summarizing the above information, the order of capability of the soil material classes may be arranged as follows:

high——V, VI, and VII
moderate——II and IV
low——I and III

Having established seven soil material classes, discriminant functions were derived for each pair of classes. The coefficients for the discriminant functions of each of $\binom{7}{2}=21$ pairs and the discriminant efficiency (Mahalanobis' distance D^2 between the two groups concerned) are given in Table 3.

The discriminant efficiency is lowest between classes I and IV, and next lowest between I and III, III and IV, and II and III, the error probability for these pairs being 4.65, 3.92, 3.51, and 3.01%, respectively. When the same 234 samples that make up the seven classes were reclassified by means of discriminant functions, four samples or about 1.7% were found to be misclassified.

All the rest of the soil samples, including the one that remained unclassified in the dendrogram, were classified into one of the seven classes by means of discriminant functions. The result of the classification is shown in Table 4. The overall distribution of the samples among the different classes is generally parallel to that of the selected samples. The greatest number of samples is concentrated in classes IV, I, and III, and the smallest number in II and VI. Altogether 156 samples belong to high capability classes (V, VI, and VII), 138 samples to intermediate classes (II and IV), and 188 samples to low capability classes (I and III).

It is interesting to note the general

Table 3 Coefficients and Discriminant Efficiency (D. E.) of the Discriminant Function for Each Pair of the Seven Soil Material Classes

	I~II	I~III	I~IV	I~V	I~VI	I~VII	II~III	II~IV	II~V	II~VI	II~VII
a_0	2.315	0.117	−0.747	5.322	2.887	3.827	−2.198	−3.062	3.008	0.572	1.512
a_1	−0.586	3.197	0.837	0.197	−3.215	0.554	3.783	1.424	0.783	−2.629	1.140
a_2	0.045	0.264	−2.675	−11.057	−2.825	−4.292	0.219	−2.720	−11.102	−2.870	−4.337
a_3	−2.048	0.719	0.651	1.031	1.949	−6.294	2.767	2.700	3.079	3.997	−4.245
a_4	2.537	2.118	−2.739	1.643	3.457	0.173	−0.419	−5.276	−0.894	0.920	−2.363
a_5	−2.765	−0.118	−0.184	−0.135	−0.064	0.109	2.647	2.581	2.630	2.701	2.874
a_6	−6.989	−4.505	−4.657	−3.422	−4.987	−4.524	2.484	2.332	3.567	2.002	2.466
D. E.	22.184	12.433	11.342	32.100	19.483	24.298	14.127	20.043	38.328	15.331	18.771

	III~IV	III~V	III~VI	III~VII	IV~V	IV~VI	IV~VII	V~VI	V~VII	VI~VII
a_0	−0.864	5.206	2.771	3.710	6.070	3.634	4.574	−2.435	−1.495	0.940
a_1	−2.360	−3.000	−6.412	−2.643	−0.641	−4.052	−0.284	−3.412	0.357	3.769
a_2	−2.939	−11.321	−3.089	−4.556	−8.382	−0.150	−1.617	8.232	6.765	−1.467
a_3	−0.068	0.312	1.230	−7.012	0.380	1.298	−6.945	0.918	−7.324	−8.243
a_4	−4.857	−0.475	1.339	−1.944	4.382	6.196	2.913	1.814	−1.469	−3.283
a_5	−0.066	−0.017	0.054	0.277	0.049	0.120	0.293	−0.071	0.244	0.173
a_6	−0.151	1.084	−0.481	−0.018	1.235	−0.330	0.133	−1.565	−1.102	0.463
D. E.	13.057	32.914	21.390	26.365	23.367	21.941	20.722	22.456	30.229	34.565

Note: The general formula for discriminant function is

$$Z(A\sim B)=a_0+\sum_i a_iF_i$$

Where a_0 is a constant, a_i is the coefficient for the i_{th} factor score, F_i. The model is designed so that positive Z indicates a sample belonging to class A and negative Z one belonging to class B.

Table 4 Distribution of the Samples from Each Country among the Seven Soil Material Classes

Soil Material Class	I	II	III	IV	V	VI	VII	Total
Bangladesh	3 (5.7)	0 (0)	11 (20.8)	39 (73.6)	0 (0)	0 (0)	0 (0)	53
Burma	1 (1.7)	0 (0)	4 (6.7)	0 (0)	0 (0)	0 (0)	55 (91.7)	60
Cambodia	3 (18.8)	2 (12.5)	10 (62.5)	1 (6.2)	0 (0)	0 (0)	0 (0)	16
East Malaysia	24 (60.0)	0 (0)	15 (37.5)	0 (0)	0 (0)	1 (2.5)	0 (0)	40
India	2 (2.8)	20 (28.2)	11 (15.5)	34 (47.9)	3 (4.2)	0 (0)	1 (1.4)	71
Indonesia	1 (2.3)	1 (2.3)	2 (4.7)	1 (2.3)	16 (37.2)	22 (51.2)	0 (0)	43
Philippines	1 (1.9)	1 (1.9)	2 (3.7)	0 (0)	28 (51.9)	18 (33.3)	4 (7.4)	54
Sri Lanka	0 (0)	8 (24.2)	9 (27.3)	9 (27.3)	7 (21.2)	0 (0)	0 (0)	33
Thailand	6 (26.1)	1 (4.3)	15 (65.2)	1 (4.3)	0 (0)	0 (0)	0 (0)	23
Vietnam	30 (61.2)	0 (0)	2 (4.1)	17 (34.7)	0 (0)	0 (0)	0 (0)	49
West Malaysia	27 (67.5)	0 (0)	9 (22.5)	3 (7.5)	1 (2.5)	0 (0)	0 (0)	40
Totai	98	33	90	105	55	41	60	482

Note: Figures in parentheses are percentages for each country.

similarity among the soils of Cambodia, East and West Malaysia, and Thailand in their distribution; they are highly concentrated in classes I and III. Likewise, Philippine and Indonesian soils are similar in falling predominantly in classes V and VI. India and Sri Lanka soils show some similarity; they are concentrated in classes II, III, and IV.

The highest concentration of soils in one class is the 92% of Burmese soils falling in class VII, followed by that of Bangladesh soils, of which more than 70% fall in class IV.

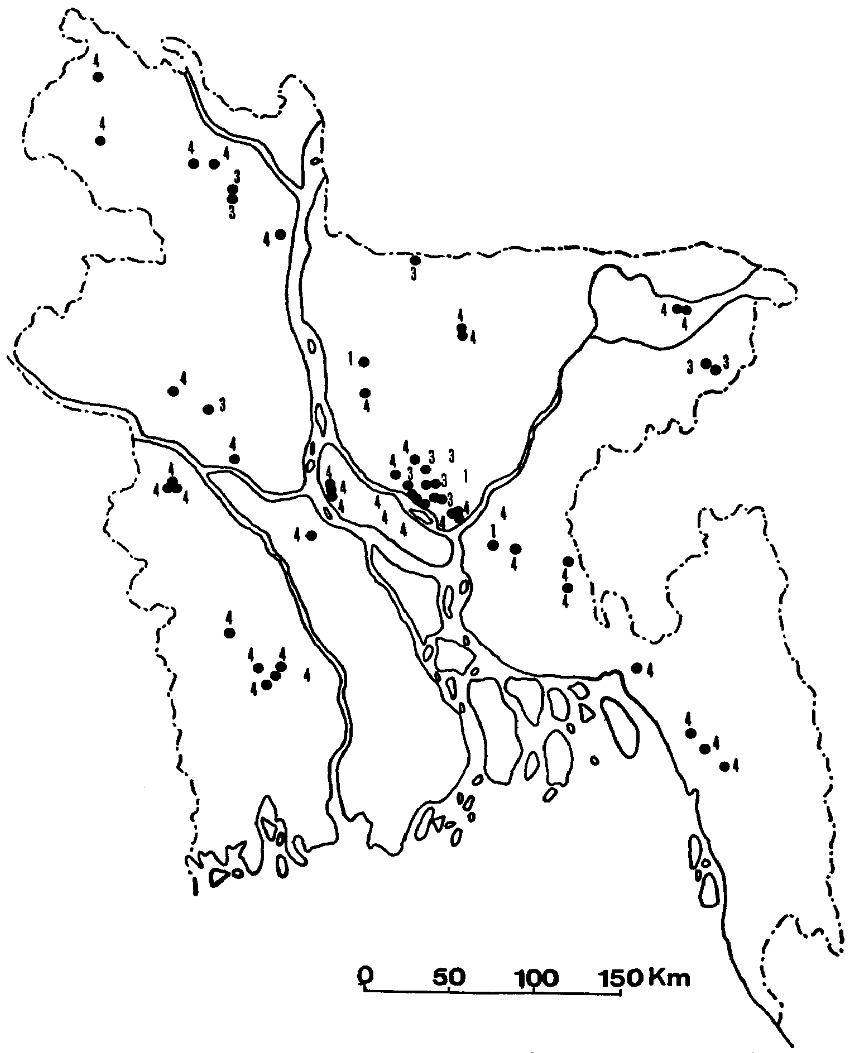

Fig. 3 Map of Bangladesh, Showing Distribution of Samples in terms of Soil Material Classes

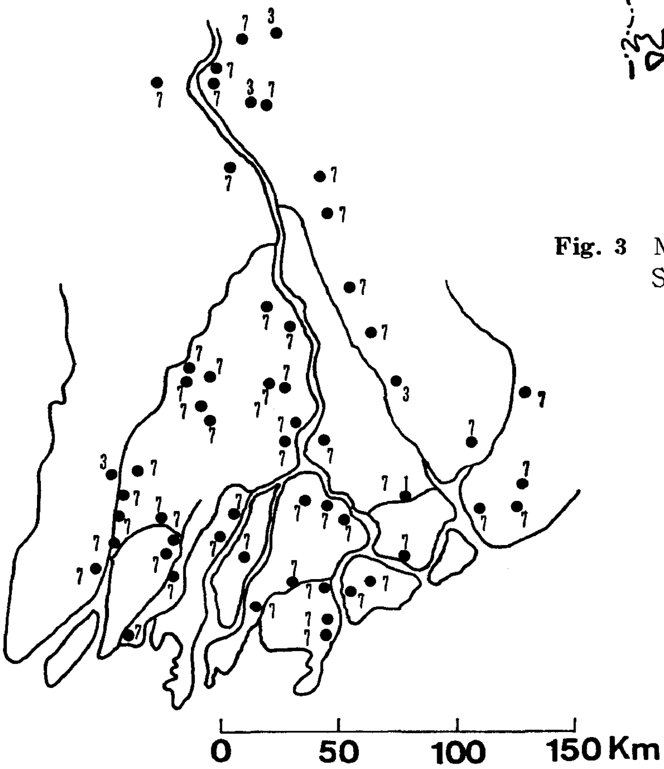

Fig. 4 Map of the Irrawaddy Delta of Burma, Showing Distribution of Samples in terms of Soil Material Classes

The geographical distribution of the samples by country was mapped in terms of soil material class, as shown in Figs. 3-13.[1)]

Bangladesh

As shown in Fig. 3, the soil samples of class IV, accounting for more than 70% of the total, occur on the Ganges and Brahmaputra sediments. Class III, about 20%, occur mostly in ter-

1) In these figures soil classes are marked with Arabic numerals, instead of Roman as used in the text, to save space.

race and piedmont areas.

Burma

From Fig. 4, the extreme uniformity of soil materials is very evident. The vast majority (92%) of the samples all belong to class VII. The soils of class III are all derived from strongly depleted sandy materials.

Cambodia

As shown in Fig. 5, many of the terrace soils fall in soil material class III, the poorest of all the soil material classes. Soils in class I are derived from lacustrine alluvium.

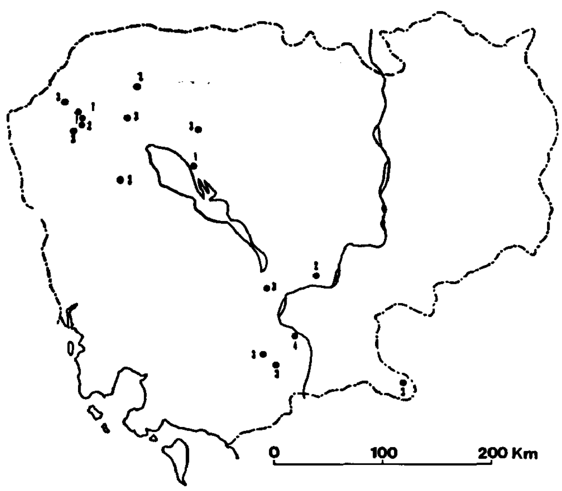

Fig. 5 Map of Cambodia, Showing Distribution of Samples in terms of Soil Material Classes

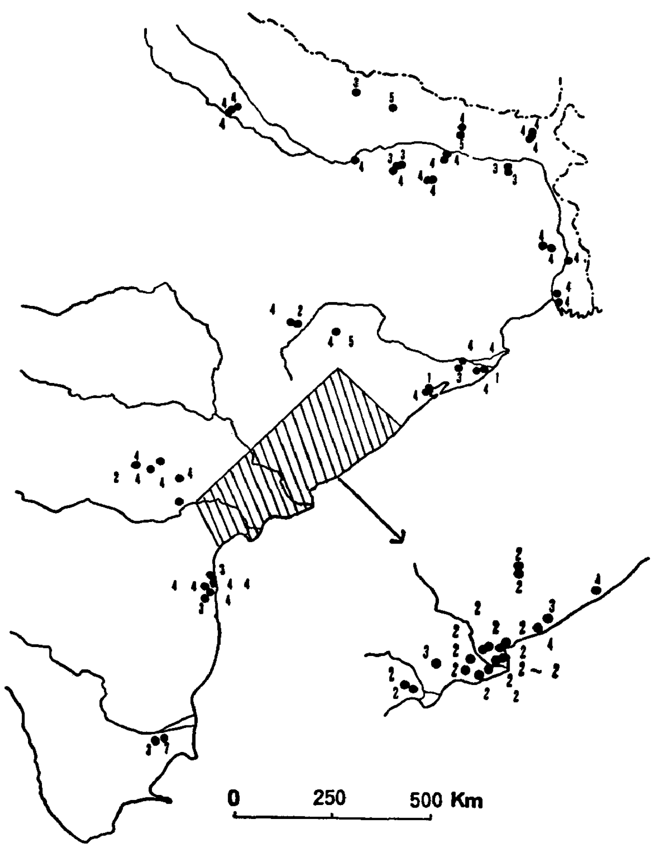

Fig. 7 Map of India, Showing Distribution of Samples in terms of Soil Material Classes

East Malaysia

As shown in Fig. 6, soil materials are generally poor. About 60% of the total fell in class I, and more than 37% in class III.

India

From Fig. 7, it can be seen that most of the soils, about 48%, are concentrated in class IV. They occur in Gangetic

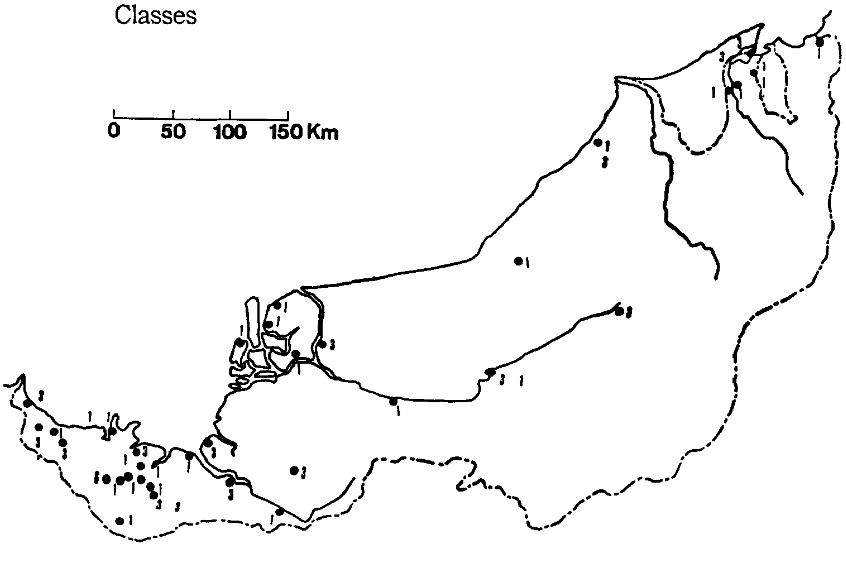

Fig. 6 Map of the State of Sarawak, East Malaysia, Showing Distribution of Samples in terms of Soil Material Classes

basin, the Hyderabad area, and around the Mahanadi delta. Most of the class II samples occur around the mouths of the Godavari and Krishna rivers. Class III samples occur on terraces of the Ganges, Godavari, Krishna, and Cauvery.

Indonesia

As shown in Fig. 8, soil material classes V and VI are dominant in Java. Class V is dominant in East Java, class VI in West and Central Java. Most of the soils from this region are derived from materials of volcanic origin.

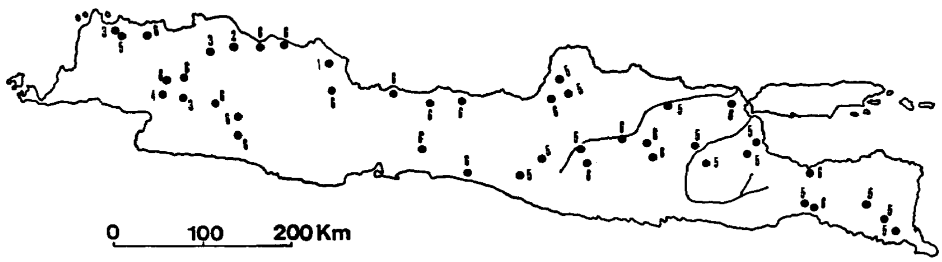

Fig. 8 Map of Java, Indonesia, Showing Distribution of Samples in terms of Soil Material Classes

Philippines

As shown in Fig. 9, soil material classes V and VI are most frequent, both being materials often encountered in volcanic regions.

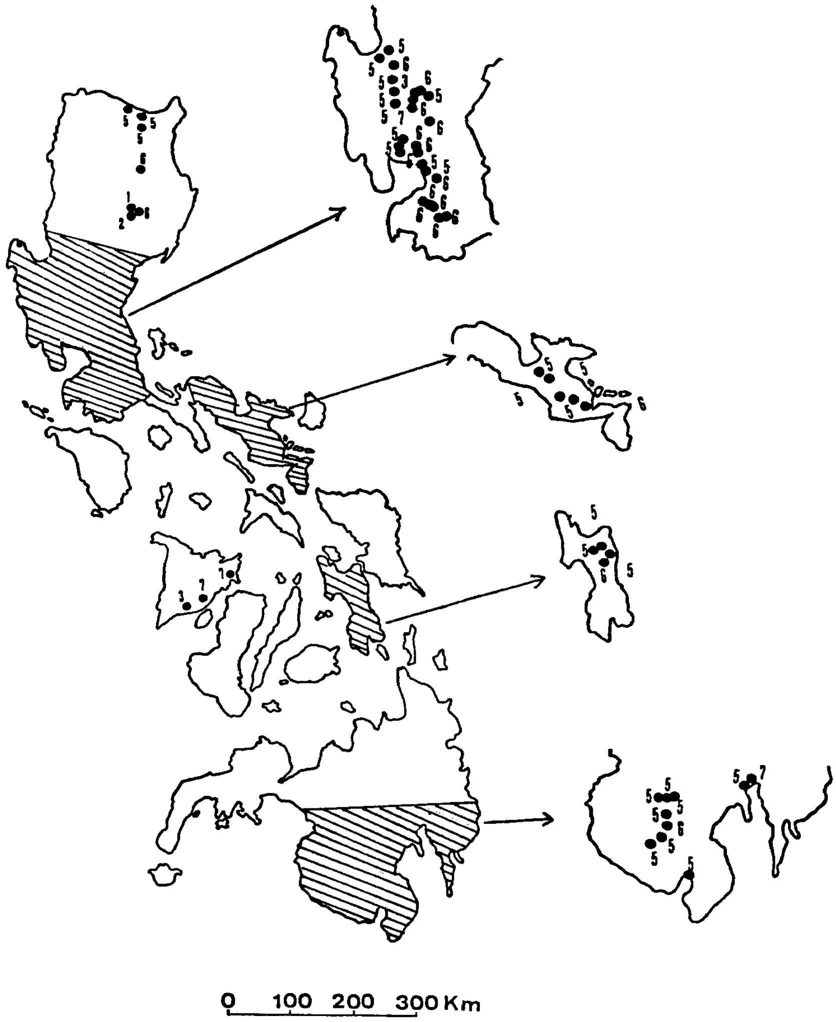

Fig. 9 Map of the Philippines, Showing Distribution of Samples in terms of Soil Material Classes

Sri Lanka

As shown in Fig. 10, soil materials are varied. Classes IV and V predominate in the dry zone, classes II and III in the intermediate and wet zones.

Thailand

As seen in Fig. 11, the dominant soil material classes are III in the Northeast and I in the Bangkok Plain. Class III is sandy, severely depleted material.

Vietnam

As shown in Fig. 12, the most widely

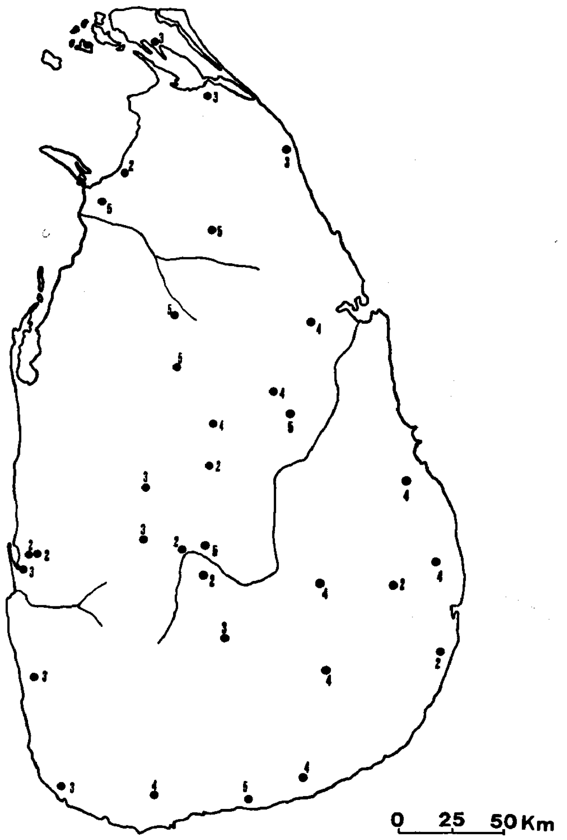

Fig. 10 Map of Sri Lanka, Showing Distribution of Samples in terms of Soil Material Classes

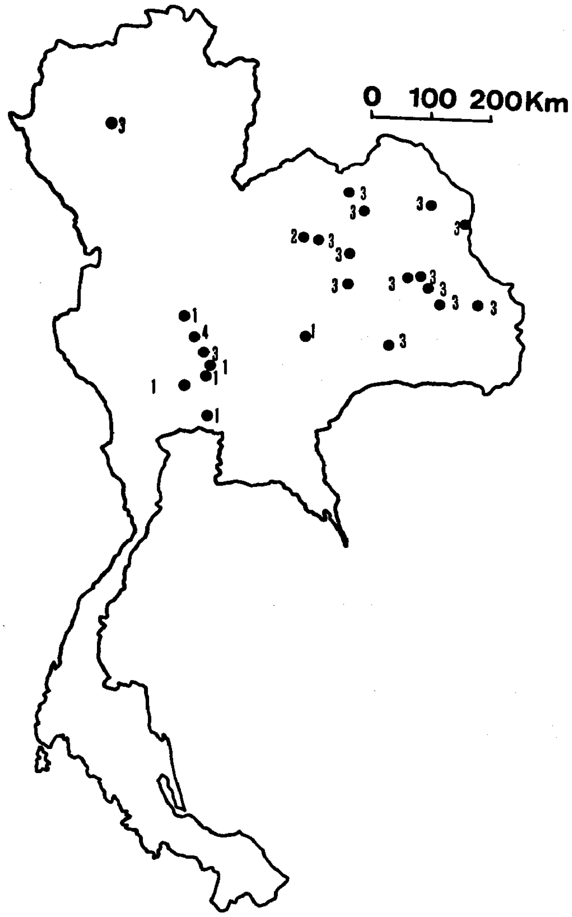

Fig. 11 Map of Thailand, Showing Distribution of Samples in terms of Soil Material Classes

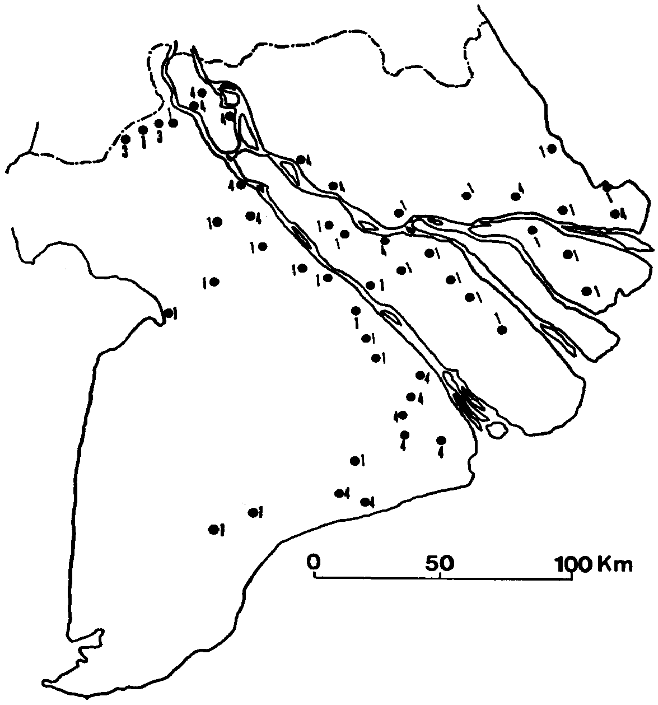

Fig. 12 Map of the Mekong Delta of Vietnam, Showing Distribution of Samples in terms of Soil Material Classes

occurring soil material is of class I. Class IV samples occur in the low and high tidal flats and in the levee areas. The two class III samples in the northwestern part of the delta are on a piedmont of granite hills and on outwashes from nearby granite hills.

West Malaysia

As shown in Fig. 13, many of the soil materials belong to class I. They are widely distributed along the east and west coasts. A fair number of class III samples occur in the same areas.

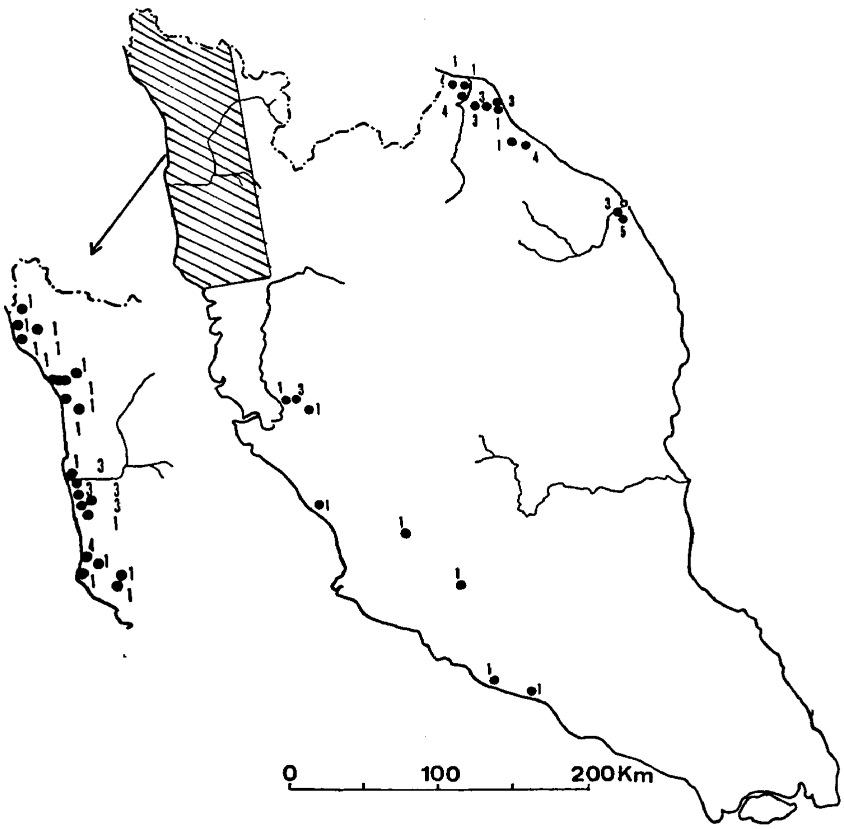

Fig. 13 Map of West Malaysia, Showing Distribution of Samples in terms of Soil Material Classes

The mean mechanical and total macro and microelement compositions for the samples in each group are given in Table 5, together with the means of such chemical and mineralogical characters related to soil materials as pH, percent base saturation (PBS), cation exchange capacity (CEC), and clay mineralogical compositions. It is clear that the general capability of the soil material classes is well reflected in their chemical and mineralogical characteristics, although the latter were

Table 5 Mean Mechanical and Total Chemical Compositions and Some Other Related Properties of the Samples in Each Material Class

Class (No. of Samples)		I (98)	II (33)	III (90)	IV (105)	V (55)	VI (41)	VII (60)	Whole (482)
Sand	%	10.06	38.18	49.40	29.03	36.39	17.49	17.13	27.98
Silt	%	33.78	18.62	25.53	34.44	26.17	28.30	41.14	30.93
Clay	%	56.16	43.20	25.08	36.53	37.44	54.22	41.75	41.10
SiO_2	%	68.91	70.12	85.57	69.40	64.31	61.18	68.19	70.94
Fe_2O_3	%	4.94	9.28	2.84	6.23	7.66	10.46	6.92	6.15
Al_2O_3	%	21.54	14.42	8.86	17.44	19.53	22.68	19.13	17.36
CaO	%	0.29	1.36	0.34	1.15	4.17	2.18	0.66	1.21
MgO	%	0.82	1.14	0.27	1.23	1.53	1.07	1.72	1.04
MnO_2	%	0.04	0.18	0.05	0.10	0.20	0.27	0.09	0.11
TiO_2	%	1.23	2.09	0.91	1.05	1.10	1.36	1.10	1.17
K_2O	%	2.13	1.30	1.20	3.29	1.30	0.64	2.09	1.92
P_2O_5	%	0.12	0.14	0.07	0.12	0.19	0.16	0.08	0.12
pH		4.59	6.42	5.32	6.12	6.69	6.46	5.10	5.65
PBS	%	62.66	95.09	59.25	91.86	98.65	94.90	84.42	80.16
CEC	me/100g	22.29	25.41	10.00	15.79	22.52	30.16	20.82	19.31

Class		I	II	III	IV	V	VI	VII	Whole
(No. of Samples)		(98)	(33)	(90)	(105)	(55)	(41)	(60)	(482)
7 Å	%	45.14	44.55	59.26	36.77	35.18	39.63	27.17	42.07
10Å	%	23.29	9.39	15.48	27.79	5.00	0.98	15.98	16.96
14Å	%	31.57	46.06	25.27	34.49	56.18	56.95	56.68	40.11
B	ppm	102	74	95	74	62	71	187	96
Cr	ppm	127	174	111	126	107	117	222	136
Co	ppm	38	80	47	53	80	78	54	56
Cu	ppm	19	62	34	30	32	41	43	33
Mo	ppm	3.0	2.6	2.3	2.9	3.1	3.1	3.1	2.9
Ni	ppm	11	34	5	18	16	7	84	22
Rb	ppm	95	34	62	132	13	7	85	75
Sr	ppm	49	79	37	92	348	176	85	108
V	ppm	164	264	109	132	193	274	162	166
Zn	ppm	60	68	37	71	70	86	93	66
Zr	ppm	126	551	294	219	170	111	112	209
S	ppm	103	12	17	16	26	21	13	35

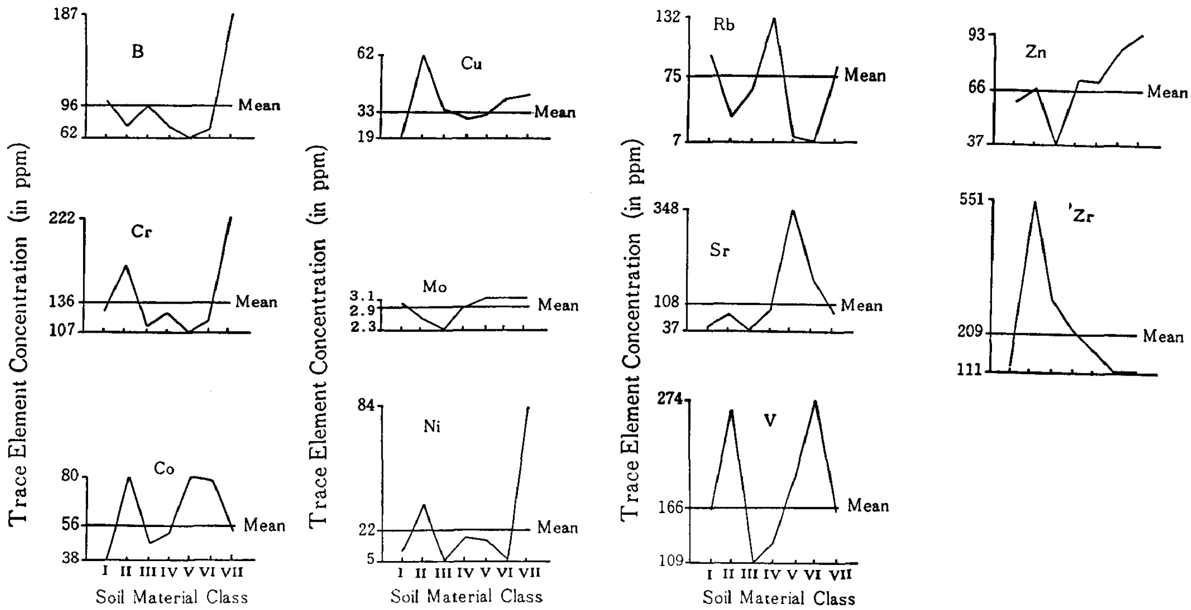

Fig. 14 Distribution Patterns of Trace Elements among the Different Soil Material Classes

not included in the process of classification.

To see clearly the differences in the distribution patterns of trace elements in the various soil material classes, Fig. 14 was prepared. From the figure, it can be seen that most of the trace elements are generally high in class VII but low in classes I, III, and IV. Class II has high amounts of chromium, cobalt, copper, nickel, vanadium, and zirconium, while class VI has high amounts of cobalt, copper, molybdenum, strontium, vanadium, and zinc. Class V showed high amounts of cobalt, molybdenum, strontium, vanadium, and zinc.

Summary

An attempt was made to reclassify Tropical Asian paddy soils with respect to their material characteristics, based on data including those of various total trace element status.

Data pertaining to contents of both macro and microelements and mechanical composition for 482 samples were processed. By factor analysis, six factors were extracted, each of which appears to represent a different aspect of soil material characteristics. The scores of the six factors were computed and used for numerical classification by means of numerical taxonomy.

Based on the dendrogram, seven classes, I-VII, were set up. Of these, two classes (I and III), containing 188 samples, were evaluated to have low capabilities as soil material; two other classes (II and IV), containing 138 samples, to be intermediate; and the remaining three classes (V, VI, and VII), accounting for 156 samples, to have high capabilities.

To facilitate objective placement of a new sample into one of the seven classes, discriminant functions were derived for each pair of classes.

Compared with the previously established material classification for Tropical Asian paddy soils, the new classification set up in the present study involves more information about different aspects of soil material characteristics, as represented by the six factors, and particularly about the trace element status.

By country, Indonesia (Java), Philippines, and Burma appear to have paddy soils with better soil materials. In contrast, the paddy soils of Cambodia, East and West Malaysia, and Thailand have generally poor materials. Bangladesh, India, Sri Lanka, and Vietnam soils have developed on materials of moderate quality.

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