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Evaluation of Soil Fertility Status of Lowland Areas in the Philippines

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Abstract

Attempts were made to evaluate the regional fertility characteristics of the Philippine lowland soils and to identify the factors determining their productivity for rice cultivation. Eight soil characters, i.e. organic C, total N, available P_2O_5, total P_2O_5, exchangeable K, available SiO_2, clay contents, and CEC for 52 surface soil samples were considered. By factor analysis, 3 factors were extracted, representing the organic matter status, available potassium and silica status, and available phosphorus status. The scores of these 3 fertility components were computed for each sample and based on the mean values for each region, regional characteristics of soil fertility status were determined. Based on the relationship between each of the 3 fertility component scores and rice yield for the 30 plow-layer samples, any of the 3 fertility components was found to be significant for rice production. Furthermore, the lowest among the 3 fertility component scores was considered to control the productivity for rice cultivation. Thus, emphasis was placed on identifying and alleviating the soil constraints, in order to achieve rational nutrient management for higher rice production.

Discipline: Soils, fertilizers and plant nutrition
Additional key words: factor analysis, fertility components, rice production, soil constraints, soil characters

Introduction

In the Philippines, the rice area has not increased since 1975, due to the limit of expansion[2]. Thus, it is necessary to increase rice production by raising the yield to meet the requirements of the rapidly growing population. In this regard, it is essential to determine the potential capability of the Philippine lowland soils for rice production and to improve nutrient management to achieve a higher yield. The characteristics and fertility evaluation of the Philippine lowland soils were reported by Kawaguchi and Kyuma[3]. Based on this information, Miura et al.[5] confirmed that the Philippine lowland soils exhibited a relatively high potential for rice production among the tropical Asian lowland soils, although some regional differences were significant, especially in the organic matter status associated with the rainfall conditions. On the other hand, based mainly on the data from the field experiments carried out during the rainy season in the Philippines, inherent productivity level and response to N rates were revealed for 4 soil orders, i.e. Entisols, Inceptisols, Mollisols, and Vertisols, although the results varied considerably due to the limited number of experiments[6]. It thus appeared that the relationship of the soil fertility status with rice production had not been well documented.

The present study aims at reevaluating the fertility characteristics of the Philippine lowland soils through the use of factor analysis of selected soil characters and to identify the constraints on rice production.

The present paper is based on part of the data obtained during the studies carried out within the framework of the UPLB/JIRCAS cooperative research program entitled "Pedological characterization of lowland areas in the Philippines (1991-1995)."

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Materials and methods

1) Study areas and samples

The soil samples used in this study covered 32 lowland soils selected from 6 lowland rice areas in the Philippines (Table 1). According to Flores and Balagot[1], the mean annual temperature in the Philippines is 27.0°C with negligible regional variations, while the mean annual rainfall is 2,533 mm with considerable regional differences ranging from 934 to 4,305 mm. By setting a value of < 100 mm rainfall for the dry months, as proposed by Manalo[4], the whole country can be divided into 3 zones from the humid to arid extreme (Fig. 1).

An attempt was made to select typical lowland soils which cover large areas in a region. At each site, soil samples were taken from each horizon for laboratory analysis. Furthermore, information pertaining to the cropping pattern, use of fertilizer, rice yield, etc. was collected from the local farmers. Rice yield here refers to rough rice yield, which may not

Table 1. Cropping pattern, rice yield, and soil classification of the sites examined

Sample designation and location		Cropping pattern	Yield ($Mg\ ha^{-1}$) Cropping season		Soil classification[a)]
			Rainy	Dry	
1) Cagayan Valley					
IS1	Echague, Isabela	Double cropping	2.8	2.3	Typic Epiaquult
IS2	Cabatuan, Isabela	Double cropping	7.3	5.5	Typic Epiaqualf
CA1	Solana, Cagayan	Triple cropping	4.0	4.0	Vertec Tropaquept
2) Central Luzon					
NE1	Muñoz, Nueva Ecija	Fallow	-	-	Oxyaquic Ustropept
NE2	Talavera, Nueva Ecija	Single cropping[b)]	5.3	-	Fluvaquentic Epiaquoll
NE3	Muñoz, Nueva Ecija	Double cropping	4.5	6.5	Ustic Epiaquert
NE4	Llanera, Nueva Ecija	Double cropping	2.3	2.3	Chromic Vertic Epiaqualf
NE5	Jaen, Nueva Ecija	Mango field	-	-	Typic Ustropept
NE6	Zaragoza, Nueva Ecija	Double cropping	4.0	8.0	Typic Epiaqualf
NE7	San Leonardo, Nueva Ecija	Double cropping	4.0	5.0	Vertic Tropaquept
NE8	San Leonardo, Nueva Ecija	Double cropping	4.0	5.8	Vertic Tropaquept
NE9	San Leonardo, Nueva Ecija	Double cropping	4.0	5.8	Ustic Epiaquert
BU1	San Miguel, Bulacan	Double cropping	6.0	6.0	Vertic Tropaquept
PA1	Villasis, Pangasinan	Single cropping[b)]	2.8	-	Fluventic Ustropept
TA1	San Manuel, Tarlac	Single cropping[b)]	4.5	-	Aeric Tropaquept
TA2	La Paz, Tarlac	Single cropping	5.0	-	Vertic Tropaquept
TA3	La Paz, Tarlac	Single cropping[b)]	5.0	-	Oxyaquic Ustropept
3) Laguna					
LA1	Santa Rosa, Laguna	Double cropping	4.0	4.0	Vertic Tropaquept
LA2	Bay, Laguna	Double cropping	5.5	5.5	Aeric Vertic Epiaqualf
LA3	Santa Cruz, Laguna	Double cropping	6.1	6.1	Fluvaquentic Endoaquoll
4) Bicol					
CS1	Milaor, Camarines Sur	Double cropping	6.0	6.0	Vertic Fluvaquent
CS2	Minalabac, Camarines Sur	Triple cropping	7.9	7.9	Vertic Tropaquept
CS3	Canaman, Camarines Sur	Double cropping	5.0	5.0	Vertic Fluvaquent
CS4	Minalabac, Camarines Sur	Triple cropping	3.3	4.5	Vertic Fluvaquent
CS5	Minalabac, Camarines Sur	Triple cropping	5.5	6.0	Vertic Fluvaquent
AL1	Polangui, Albay	Double cropping	4.4	6.0	Typic Tropaquept
SO1	Casiguran, Sorsogon	Double cropping	5.0	4.3	Vertic Fluvaquent
5) Iloilo					
IL1	Sara, Iloilo	Double cropping	3.5	3.0	Vertic Tropaquept
IL2	San Miguel, Iloilo	Double cropping	7.8	6.3	Vertic Tropaquept
6) Cotabato					
CO1	Cotabato, Maguindanao	Single cropping	2.0	-	Vertic Fluvaquent
CO2	Tacurong, Sultan Kudarat	Double cropping	4.0	4.0	Vertic Tropaquept
CO3	Kabacan, North Cotabato	Double cropping	6.0	7.0	Typic Tropaquept

a): Based on Soil Taxonomy[8].
b): Field crops such as vegetables or tobacco were cultivated in the dry season.

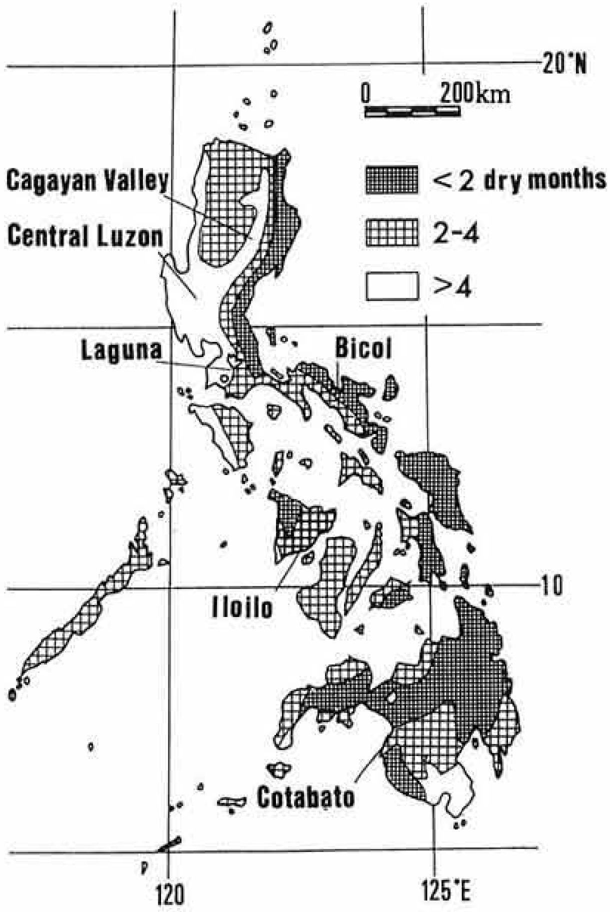

Fig. 1. Classification of climatic zones in the Philippines based on the number of dry months

be a quantitative parameter but indicates the representative value for a long period of time under normal growth. As shown in Table 1, rice cultivation was practiced at 30 of the 32 sites examined. For the 24 sites with double or triple cropping of rice, a larger amount of fertilizer was applied in the dry season than in the rainy season since growth was more vigorous in the dry season due to the larger number of sunshine hours. As a result, in general, rice yield was higher in the dry season cropping (average of 5.3 Mg ha^{-1}) than in the rainy season one (4.7 Mg ha^{-1}), although significant differences in rice yield among the sites were observed. In the present paper, rice yield of the rainy season cropping was selected for analysis, since more data were available. As for the rice cultivars, high-yielding modern varieties were adopted except for 1 site, i.e. CO1. In the Philippines, almost 3 million ha or 94% of the total rice area were planted to modern varieties in 1992[2)].

2) Analytical methods

For the soil chemical analysis, the air-dried fine earth samples (<2 mm) were ground to pass through a 0.5 mm mesh sieve. The amount of organic C was determined by wet combustion with a mixture of $K_2Cr_2O_7$ and H_2SO_4 (Walkley-Black procedure). Total N content was determined by digestion with H_2SO_4, distillation and titration (Kjeldahl procedure). Available P_2O_5 was extracted with an acidic ammonium fluoride and the content was determined by spectrophotometry (Bray & Kurz No. 2 procedure). The total content of P_2O_5, was determined by X-ray fluorescence spectrometry using samples subjected to a pressure of 20 t/cm^2 for 1 min. The exchangeable bases were extracted with 1 M NH_4OAc (pH 7.0) by percolation. The amounts of exchangeable Ca and Mg were determined by atomic absorption spectrophotometry, and that of exchangeable K by flame emission spectrophotometry. After replacement of exchangeable bases with NH_4OAc, washing with ethanol and replacement of NH_4^+ with 100 g L^{-1} KCl were successively performed by leaching. To measure the CEC of the sample, NH_4-N content was determined by distillation and titration. Available SiO_2 was extracted with an acetate buffer solution (pH 4) and the content was determined by spectrophotometry.

For particle size analysis using the fine earth samples, the silt (2 to 20 μm) and clay (<2 μm) fractions were analyzed by the pipette method, after removal of organic matter with H_2O_2 and free Fe oxides by the DCB method, and dispersion with NaOH.

3) Statistical methods

For the statistical analysis, 52 surface samples among the 32 soils examined were processed. In order to characterize these surface soil samples, a factor analysis was adopted[7)]. Factor analysis aims at transforming the original set of correlated variables into a new set of mutually uncorrelated variables in such a way that a few factors represent a large proportion of the total variance in the original data.

In the course of preliminary trials, various attempts were made to select the variables which should be subjected to the final factor analysis. A set of 8 characters, i.e. organic C (OC), total N (TN), available P_2O_5 (AvP), total P_2O_5 (TP), exchangeable K (ExK), available SiO_2 (AvSi), clay (Clay) contents, and cation exchange capacity (CEC) of the 52 surface soil samples was used in the final factor analysis.

Table 2. Eigenvalues, cumulative percentage of the total variance, factor loadings of the 3 factors, and communality estimates of the 8 soil characters

	Factor 1	Factor 2	Factor 3	Communality
Eigenvalue	3.21	1.74	1.44	
Cumulative (%)	40.1	61.9	79.9	
Soil character				
OC	0.926	0.025	0.056	0.860
TN	0.928	-0.015	0.029	0.862
AvP	-0.269	0.200	0.807	0.763
TP	0.325	-0.139	0.779	0.731
ExK	0.046	0.792	0.291	0.714
AvSi	0.148	0.872	-0.251	0.846
Clay	0.884	0.189	-0.118	0.832
CEC	0.713	0.507	0.139	0.785

Results and discussion

1) Extraction of fertility components

Based on the factor analysis, 3 factors with eigenvalues larger than 1 were extracted, which together accounted for about 80% of the total variance, as shown in Table 2, implying that these 3 new compound characters retain most of the information in the original variables.

As seen from the final factor loadings after varimax rotation (Table 2), Factor 1 was significantly related to OC and TN. Highly positive loadings on Clay and CEC reflected the control of organic matter accumulation by the clay content and the contribution of the amount of organic matter to CEC, respectively. Much lower factor loading on TP was ascribed to organic phosphorus to some extent. Thus, Factor 1 which was considered to be related to the characters determined by the amount of organic matter, was thought to represent the "organic matter status (OM)." Factor 2 which was highly related to ExK and AvSi, represented the "available potassium and silica status (AK&Si)." Moderately high loading on CEC may be related to the base status, since positive correlations of the score of Factor 2 with exchangeable Ca ($r = 0.498$, significant at the 0.1% level) and with exchangeable Mg ($r = 0.473$, significant at the 0.1% level) were observed. Factor 3 clearly represented the "available phosphorus status (AP)," since the contribution of the other variables except for AvP and TP was negligible.

Therefore, it can be considered that these 3 fertility components which are mutually independent, represent different aspects of soil fertility.

2) Regional characteristics of the 3 fertility components

The factor scores were computed for individual soil samples in order to evaluate numerically the fertility characteristics of the lowland soils examined. The scores computed for the samples were standardized with a mean of zero and a variance of unity. Therefore, positive score values indicate above-average status with reference to the overall mean for the 52 sample soils, while negative values below-average status.

The mean values of the 3 fertility component scores estimated for each of the 4 regions on Luzon Island are shown in Fig. 2. The mean values for the Iloilo and Cotabato regions were not used for the analysis due to the limited number of samples. The highest OM score was found in Bicol, due to

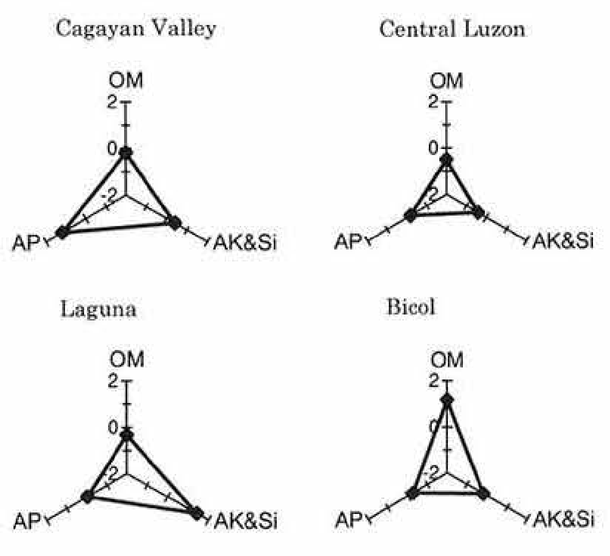

Fig. 2. Pattern of the mean fertility component scores for the 4 study areas

the highest mean of OC, TN, and Clay. The highest mean of OC and TN was likely to be associated with the effect of humid climatic conditions on the accumulation of organic matter in Bicol (Fig. 1). The highest mean of Clay may be ascribed to the topography of the sampling sites, mostly on or near the back swamps of the lower reaches of the Bicol River. On the other hand, the lowest mean of OM score was observed in Central Luzon under the much drier climatic conditions (Fig. 1), although the 3 samples located on or near the back swamps with relatively high Clay, OC, and TN, showed exceptionally positive scores.

The mean AK&Si score was highest in Laguna, while the lowest in Central Luzon. However, appreciable differences in the score were observed among the Cagayan Valley samples: 1 sample on the river terrace showed a very low score, while 2 samples on the valley plain very high scores. The moderately positive correlation of the AK&Si score with the CEC/Clay ratio ($r = 0.523$, significant at the 0.1% level) may indicate that available potassium and silica status is associated with the nature of clay, determined by the parent materials or degree of weathering, or both.

The mean AP score was by far the highest in Cagayan Valley, although 1 sample on river terrace showed a very low score. On the other hand, the lowest score was recorded in Bicol, although 2 samples showed very high scores, one of them located on the flood plain in the vicinity of the foot of a mountain where unweathered materials can be easily transported. The weak positive correlation between the AP score and CEC/Clay ratio ($r = 0.400$, significant at the 1% level) roughly indicates that the available phosphorus status is related to the nature of clay.

The above results on the regional characteristics are in agreement with those obtained previously[5], suggesting that the adoption of a factor analysis is valid.

3) Limiting factors to rice production

To analyze the relationship between the soil fertility status and rice yield, a plow-layer soil sample was used here for each of the 30 lowland soils under rice cultivation in the 6 study areas. Based on the relationship between the OM score and rice yield, it appeared that the samples with a higher score tended to show a higher rice yield, except for the 6 samples with relatively high OM scores (Fig. 3a), suggesting that organic matter exerts a beneficial effect on rice production. The lower rice yield than expected from the OM score for the 6 samples may be ascribed to some factors, as shown in Table 3. The lowest rice yield in 1 sample from Cotabato, CO1 should be attributed to the cropping of a traditional cultivar which can not attain a higher yield, since no particular constraints were identified from the 3 scores. For the other 5 samples, either of the other 2 fertility components showing a lower score may be significant for determining rice production. As for the relationship between the AK&Si score and rice yield, samples with a higher score tended to show a higher yield, except for 5 samples, indicating the beneficial effect of available potassium and silica (Fig. 3b). The limiting fertility components for the 5 samples could be deduced from Table 3. A similar trend was observed from the relationship between the AP score and rice yield (Fig. 3c), except for 6 samples (Table 3).

Based on the above results, all the 3 fertility components appeared to play a significant role in rice production. Based on the law of the minimum

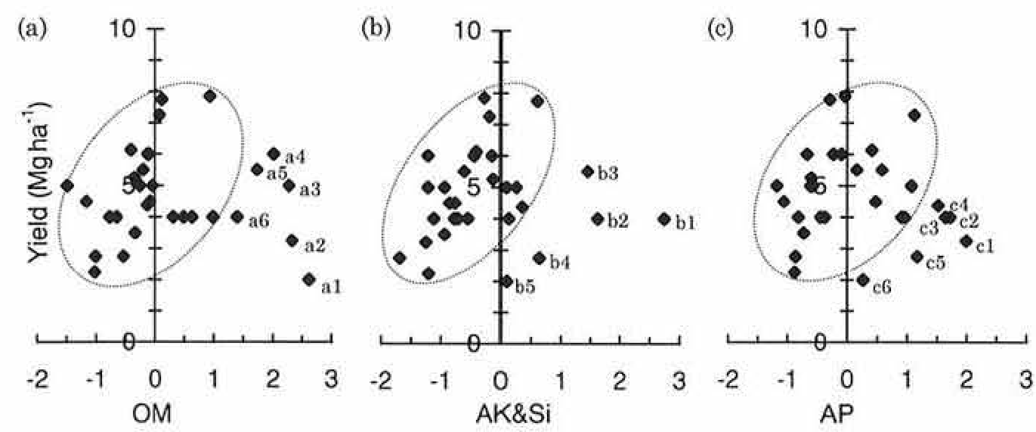

Fig. 3. Relationship between each of the 3 fertility component scores and rice yield

Table 3. Three fertility component scores for exceptional samples

No.[a)]	Region	Sample	OM	AK&Si	AP	Yield (Mg ha^{-1})
1) Exceptional samples for the relationship between OM score and rice yield						
a1	Cotabato	CO1	2.61	0.09	0.27	2.0
a2	Bicol	CS4	2.33	−1.25	1.99	3.3
a3	Bicol	CS3	2.27	0.25	−0.57	5.0
a4	Bicol	CS1	2.01	−0.14	−0.67	6.0
a5	Bicol	CS5	1.73	−0.60	0.17	5.5
a6	Central Luzon	NE8	1.39	−1.11	0.95	4.0
2) Exceptional samples for the relationship between AK&Si score and rice yield						
b1	Laguna	LA1	0.49	2.75	−0.44	4.0
b2	Cagayan Valley	CA1	0.31	1.62	1.63	4.0
b3	Laguna	LA2	−0.20	1.45	0.58	5.5
b4	Central Luzon	PA1	−0.54	0.64	1.17	2.8
b5	Cotabato	CO1	2.61	0.09	0.27	2.0
3) Exceptional samples for the relationship between AP score and rice yield						
c1	Bicol	CS4	2.33	−1.25	1.99	3.3
c2	Cotabato	CO2	−0.77	0.12	1.72	4.0
c3	Cagayan Valley	CA1	0.31	1.62	1.63	4.0
c4	Bicol	AL1	−0.14	0.35	1.52	4.4
c5	Central Luzon	PA1	−0.54	0.64	1.17	2.8
c6	Cotabato	CO1	2.61	0.09	0.27	2.0

a): The number corresponds to the number indicated in Fig. 3.

Table 4. Three fertility component scores for the samples with lowest 6 rice yields

Region	Sample	OM	AK&Si	AP	Yield (Mg ha^{-1})
Cotabato	CO1[a)]	2.61	0.09	0.27	2.0
Central Luzon	NE4	−1.03	−1.20	−0.88	2.3
Cagayan Valley	IS1	−1.01	−1.69	−0.86	2.8
Central Luzon	PA1	−0.54	0.64	1.17	2.8
Bicol	CS4	2.33	−1.25	1.99	3.3
Iloilo	IL1	−0.34	−0.94	−0.73	3.5

a): The lowest rice yield was caused by the cultivation of a traditional variety.

according to which any essential nutrient with a deficient level determines crop production, any fertility component with the lowest level may control rice yield. As shown in Table 4, the possible cause of low rice yield of <4 Mg ha^{-1} could be identified for the 6 samples. In the case of 3 samples, NE4, IS1, and IL1, all the 3 scores showed negative values, indicating that all these constraints could be responsible for the low rice yield.

Therefore, it is essential to determine the actual soil fertility status in individual rice fields, e.g. through soil diagnosis, in order to identify and alleviate soil constraints on rice production. Rational nutrient management involving adequate and balanced fertilizer application should be applied in the Philippine lowland soils, in order to increase rice production or to secure a stable supply as a whole.

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