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ABSTRACT

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Twelve Indonesian, mainly paddy soils, were compared with six Japanese soils and their characteristics were analysed by physical and chemical methods. The soils were divided into four groups according to their phosphate sorption coefficient and various soil parameters such as CEC and contents of clay, free iron, exchangeable Ca and organic carbon. To evaluate the phosporus availability of paddy soil by using soil testing methods, wet or submerged samples of soils should be extracted, because the availability of phosphorus is greatly influenced by submergence.

Among the soil testing methods applied to the submerged soils, Bray II method showed a highly significant correlation with P uptake by rice seedlings grown on soils except for neutral and alkaline soils rich in Ca-P. The Olsen-EDTA method consisting of extraction with 0.5 M $NaHCO_3$-0.02 M EDTA at pH 8.5 was proposed by the authors since it was found to be applicable to a wider range of paddy soils. Pot and field experiments with various soils were carried out to determine the effect of phosphate application on the growth and yield of rice plants. Although a remarkable response to phosphate was observed in the tillering capacity of rice plants grown in a Reddish Brown Latosol, no significant yield differences were recognized among the phosphate levels applied. The amount of phosphate required to produce a unit weight of rice grain was nearly the same as that for temperate rice.

Severe phosphorus deficiency occurred in the newly opened paddy fields with Red-Yellow Podzolic soil. The amount of phosphate application recommended for such fields was estimated to be 100 kg/ha, with which the critical Bray II-P value of 15 ppm P can be maintained in the soil.

Phosphates in the solid phase of Grumusol or a soil rich in calcium phosphate become available when the pH decreases after submergence. Application of 20 kg P_2O_5/ha of readily soluble phosphate is recommended to compensate for the phosphorus deficiency in the early growth stage of rice plants in such soils. In Java, most of the Regosols and Alluvial soils derived from pyroclastic materials are rich in phosphate. Phosphate application is not necessary in those soils which have a high content of total and available phosphate.

Index words: phosphorus in soil, phosphorus fertilizer, phosphorus deficiency in soil, soil test values

CONTENTS

Phosphate Response of Rice in Indonesian Paddy Fields*

I Introduction

Wetland rice has been cultivated in various regions in Indonesia from the highlands to the lowlands from time immemorial. The complexity of the climatic, geological and topographical conditions has produced soils of various characteristics. Consequently, paddy soils in Indonesia have a wide range of features.

Soils of Indonesia were classified into the following great soil groups (DUDAL and SOEPRAPTOHARDJO, 1957): Latosols, Andosols, Red-Yellow Podzolic soils, Red-Yellow Mediterranean soils, Regur soils, Podzols, Paddy soils, Hydrosols, Calcisols, Regosols, Lithosols, Alluvial soils and Organic soils. Regur soils which were once called Margalite soils, are referred to as Grumusols in the present Soil Maps published by the Soil Research Institute.

According to SOEPRAPTOHARDJO (1957), DUDAL and MOORMANN (1964) and KYUMA (1969) the distribution patterns of those soil groups are as follows: under tropical rain forest climate, Latosols were developed on neutral to basic volcanic rocks, and Andosols replaced them at higher elevations on the volcanoes; Red-Yellow Podzolic soils derived from acid parent materials, such as acid volcanic ashes and quartziferous sedimentary rocks cover lowlands; in the regions where a dry season predominates Red-Yellow Mediterranean soils are distributed on limestone hills while Grumusols occupy lowlands where basic volcanic ashes and outwash from limestone hills have been deposited; parent materials of Regosols are either sand of sand dunes along the sea coast, newly deposited volcanic ash which is most important for agricultural use, or colluvial deposits; Alluvial soils are distributed in riverine and marine lowlands.

Among those soil groups, the Latosols and Alluvial Soils are the most important soil groups in irrigated paddy fields. A few paddy fields have also been found on Andosols. Although shifting cultivation used to be a common practice in the regions of Red-Yellow Podzolic soils, some of the areas have been changed to paddy fields with irrigation systems. A few rainfed paddy fields are scattered on the Red-Yellow Mediterranean soils. Paddy fields are commonly found on the lowland soils such as Alluvial soils, Grumusols, Regosols originating from volcanic ash, and various hydromorphic soils.

TANAKA and YOSHIDA (1970) in their book on the nutritional disorders of the rice plant in Asia reported that phosphorus deficiency with iron toxicity occurred on the Lateritic soils in Jave. Afterwards, TANAKA et al. (1970) made a similar survey in Java, and reported phosphorus deficiency in the areas with Grumusols. They pointed out the possible occurrence of phosphorus deficiency in the soils with high pH in Central Java and the soils with low pH and high iron content in West Java.

In 1970, the Soil Research Institute in Bogor compiled and published the Soil Map of Java and Madura (scale 1:250,000) showing phosphate status in paddy field areas (SUDJADI, 1973). Up to now, however, appropriate and efficient doses of phosphates for fertilization have not been established for each soil group, because basic information on phosphate application to wetland rice remained fragmentary.

In the BIMAS project (a project for increasing food production through providing

* Paper based on the senior author's dissertation thesis presented at Hokkaido University

credit for agricultural inputs and guidance in cultivation techniques) the doses of N and P fertilizers were indicated according to the local or new high-yielding varieties. SUPARTONO (1973) carried out fertilization experiments in modifying the doses according to the regions (soils).

In relation to the above mentioned fertilizer experiment program this study aimed to set up criteria for determining the dose of phosphorus to be applied, through the evaluation of the phosphorus supplying ability of each soil group, the reactions of soils to fertilizer phosphates, and the effect of soil and fertilizer phosphorus on the growth and yield of wetland rice.

Following is the outline of previous works concerning the forms of soil phosphorus and their transformation and fertilization with phosphates.

Forms of phosphorus compounds in soils and their availability

Soil phosphorus can be divided into organic and inorganic forms and the latter is mainly present in the solid phase with part of it being dissolved in the soil solution (liquid phase). The concentration of phosphorus in the soil solution is very low, ranging from 10^{-4} — 10^{-8} M, usually about 10^{-5} M (0.3 *ppm* P) (RUSSELL, 1973, p. 573). Therefore, the ability of a soil to supply phosphorus for a crop is determined not only by the absolute value of the phosphorus concentration in the soil solution (intensity factor), but also by the recovery rate of phosphorus in the soil solution which is depleted by plant uptake (capacity factor).

When a water soluble phosphatic fertilizer such as calcium superphosphate is applied to a soil, most of the phosphate is rapidly sorbed by the soil and gradually changed to a hardly soluble form.

The fixation of fertilizer phosphate and the transfer of soil phosphate from the solid phase to the soil solution are markedly influenced by various soil properties as well as the chemical forms of the phosphates.

There are two methods for studying the existing forms and the changing processes of inorganic phosphates in soils. One is the selective extraction method by various reagents, such as the Chang-Jackson method (CHANG and JACKSON, 1957), and the other is the solubility (activity) products method.

Selective extraction method

In the Chang-Jackson method, soil was extracted with neutral 0.5 N NH_4F, 0.1 N NaOH and 0.5 N H_2SO_4 successively, and the respective fractions were referred to as Al-P, Fe-P and Ca-P. The dithionite-citrate soluble fraction of the remaining soil was referred to as reductant soluble-P, and the neutral 0.5 N NH_4F extractable fraction as occluded Al, Fe-P. PETERSON and COREY (1966) somewhat modified the method with regard to the order of extractions and the extracting reagents.

After testing the Chang-Jackson method on Japanese soils, EGAWA and SEKIYA (DOJOYOBUN SOKUTEIHO IINKAI, p. 235) proposed a modified method, in which the fractions of successive extraction with 2.5 % acetic acid, 1 N NH_4F (pH 7.0) and 0.1 N NaOH are referred to as Ca-P, Al-P and Fe-P, respectively. The principle of these fractionation methods of soil inorganic phosphates is based on the selective solubility of each reagent. As the selectivity of a reagent has a rather broad range and the phosphates in soils assume many complicated forms, the content in each fraction can not be defined exactly as Ca-P, Al-P, etc. The selective extraction methods, however, were adopted in many studies on soil phosphorus due to the simplicity of the procedures.

CHIANG (1963 a, b, 1965) in Taiwan studied the chemical changes of soil and fertilizer phosphorus in paddy fields in applying the Chang-Jackson method and showed that the final form of phosphorus in acid soils was mainly Fe-P and in alkaline soils Ca-P; rice response to Ca-P was stronger in soils rich in Fe- and Al-P, whereas the response to Al- and Fe-P was stronger in neutral or alkaline soils rich in Ca-P. He also reported that among the soil testing methods for available phosphorus, Bray II-P values showed a close correlation with the rice yields in the field without P application; but in order to further increase the accuracy of testing the method should be modified.

A number of studies were concerned with the relation between the crop yield or the phosphate uptake by crop and the soil test value or the concentration of P in each fraction. For example, KHANNA (1967), using Indian soils of pH 6.8—8.2, carried out studies along the same lines. Assuming that the saloid bound P (P dissolved in 1 N

NH_4Cl), Al-P and Fe-P are important in plant nutrition, he deduced that the Olsen, Bray I, and DATTA and KAMATH (versene-fluoride) methods gave better measurements of plant-available P. SUZUKI et al. (1963) determined various P parameters in Michigan soils. Short-term uptake of P by barley in the greenhouse was highly correlated with the values obtained by the Truog P, while A-values were highly correlated with those obtained by the Olsen, resin, and Bray I method. Organic P and Fe-P did not contribute to the P removed by any of the methods. Truog P method apparently removed portions of both the Ca-P and Al-P fractions, and P removed by cropping was also derived from these two fractions. All the other measurements were highly correlated with only Al-P.

MAHAPATRA et al. (1969) studied the transformation of soil inorganic phosphorus under submerged conditions. Bray II P determinations of air-dried soils were correlated with water soluble, easily soluble P, Al-P and Ca-P, whereas those of submerged soils were correlated with Fe-P, Ca-P and Al-P. As the importance of Fe-P increased with submergence, P values of air-dried soil obtained by the Bray II-P method failed to evaluate paddy soils properly. Similar investigations were carried out by CHOLITKUL and TYNER (1971) in Thailand who suggested that the Olsen P method afforded a better measurement in paddy soils due to its higher correlation with Fe-P. The best reagent for submerged soils should be able to extract Fe-P specifically. DJOKOSUDARDJO (1974) adopted the same techniques in his studies on the behavior of phosphorus in Indonesian soils and showed that (1) some alluvial soils and regosols of volcanic ash origin were very rich in Ca-P, (2) the phosphate added to a soil was first changed to Al-P and then to Fe-P, (3) the P uptake by oat seedlings during 15 days correlated with the P values of Bray I, II or North Carolina methods but not with those of the Olsen method.

Summing up the many studies on soil testing methods for available phosphorus in paddy soils, CHANG (1964, 1976) stated that the Olsen and Bray I methods were universally applicable to many soils because (1) Fe-P which pre-dominates in paddy soils is extractable with the alkaline solution of the Olsen method or with the weakly acid solution containing floride of the Bray I method, and (2) although Ca-P in the coarser particles of calcareous soils is hardly available, it is soluble in the strong acid extracting solution of Truog or Bray II method, thus it is likely that the availability would be overestimated with those methods, while the former two methods are free from such a possibility.

SHIGA (1973, 1976) applied the Bray II method to wet paddy soils for extracting Fe-P and obtained satisfactory results. All the soil testing methods so far were proposed for upland or air-dried soils. As there is a marked difference in phosphorus availability between the oxidative and reductive conditions of soils, reductive or submerged wet soils should be used for testing paddy soils.

Solubility products method

If the concentration of phosphate in the soil solution is controlled by the solubility of hydroxy-apatite, the equation $10\ (pH - 1/2\ pCa) - 3\ (pH + pH_2PO_4) = 14.7$ (25°C) can be composed (RUSSELL, 1973, p. 561). The equation can be expressed as a straight line in the graph of ($pH - 1/2\ pCa$)—($pH + pH_2PO_4$) or (pH)—(pH_2PO_4) in taking into account environmental conditions such as CO_2 concentration in the air. The solubility products were measured on various synthetic Ca-P, Al-P and Fe-P, or computed thermodynamically for drawing the theoretical solubility diagrams. Then the pH and the concentration of phosphates were determined on an actual soil to calculate pH_2PO_4 and the values were plotted on the diagram. The chemical form of phosphate in the soil can be detected on the diagram (ERIKSON, 1952; LINDSAY and MORENO, 1960; BACHE, 1963;

WEIR and SOPER, 1963).

ONIKURA (1963) determined the concentration of Al and P in the acetate buffer extract of a volcanic ash soil under a certain ionic strength. From the results obtained, pK = pAl + pH_2PO_4 + 2pOH was calculated and the pK values obtained were compared with the pK of variscite, 29.53. The comparison showed that variscite-like aluminum phosphates were present in the volcanic ash soils and that the higher the concentration of added phosphate, the higher the solubility of the resulting aluminum phosphate. In his determinations of the phosphate equilibria of several Japanese andosols, Red-Yellow Podzolic soils and Alluvial soils in 0.01 *M* $CaCl_2$ solution, WADA (1964) observed that the phosphate activity was close to that of the variscite-gibbsite system or the strengite-ferric hydroxide system below pH 5.2, but with pH 5.2—7.0 the solubility products method could not be applied, due to the occlusion of phosphate by iron and aluminum oxides.

HANADA (1965) studied the phosphate equilibria of volcanic ash soils in Aomori Prefecture and concluded that when P/Al was low an equilibrium between phosphate fertilizer and aluminum in the soil was quickly reached to form variscite and when P/Al was high it was hardly reached, suggesting that a part of the phosphates remained in the active form. This study is similar to the observation of ONIKURA mentioned previously.

TANAKA, WATANABE and ISHIZUKA (1969) added phosphate to 5 paddy soils, plotted the activities of ions in the soil solution on the solubility diagram, and reported that the $Al(OH)_2 \cdot H_2PO_4$ complex which was formed in acid soils became stabilized as variscite-gibbsite system in the development of reduced conditions while with the rise of pH and the presence of an adequate amount of calcium it was shifted to the Ca-P system. The fact that the pH values of submerged soils usually converge to 6.7 and that around this pH value there is an intersection between the curve of the gibbsite system and that of the hydroxyapatite system on the (pH) - (pH_2PO_4) diagram may account for the increase in phosphorus availability under the submerged conditions.

KONNO and KOBO (1970) measured the activities of various ions in the solution percolating through a tube filled with a paddy field soil and demonstrated the presence of octacalcium phosphate in the solution from a degraded paddy soil, of vivianite-like ferrous phosphate in the solution from an ordinary paddy soil and of variscite-like aluminum phosphate in the solution from a volcanic ash soil.

Phosphorus fixation by soil and availability of soil phosphorus

The relation between the amount (Y) of P sorbed by 1 g of a soil from a dilute phosphate solution and the concentration (C) of P left in the solution is known to follow the Langmuir equation of adsorption isotherm $C/Y = C/S + 1/KS$ (RUSSELL, 1973, p. 568). In the equation, constants K and S respectively represent the bond energy and the phosphate maximum adsorption of the monomolecular layer covering the adsorption surface.

WOODRUFF and KAMPRATH (1965) set up the Langmuir isotherms of soils to determine the P adsorption maxima (capacity) and expressed the doses of fertilizer applied as saturation degrees of the capacity in the fertilizer experiment of millet. In soil with higher capacity, lower saturation of fertilizer gave the maximum yield, but soil with lower capacity required 100 % fertilizer saturation. In both cases, the phosphate concentration in the soil solution was above 10^{-5} *M* (0.3 ppm).

FOX and KAMPRATH (1970) measured the phsphorus concentration in a 0.01 *M* $CaCl_2$ extract of soils to which increasing rates of calcium phosphate were added, and set up the equations of phosphate adsorption isotherm. The amount of fertilizer phosphate applied which maintained a value of 0.2 *ppm* P in the soil solution resulted in a 92—99 % maximum yield of pearl millet. DJOKOSUDARDJO (1974) also set up equations for Indonesian soils to determine the constants K and S and the amount of P necessary to maintain a concentration of 0.2 *ppm* in the soil solution and concluded that Andosols require a large amount of phosphate followed by Mediterranean soils and Ultisols, whereas Alluvial soils and Regosols which are rich in Ca-P require little phosphate. However, he did not carry out field experiments at these fertilizer doses.

KHALID, PATRICK and PETERSON (1979) studied the relation between rice yields in field experiments performed in Louisiana State and estimated the amount of P necessary for maintaining 0.2 *ppm* P in the soil solution under anaerobic conditions. They observed a correlation between both factors only in the case of Crowley silt loam.

Phosphate uptake by plants

A soil nutrient reaches the crop roots in three ways: mass flow, diffusion and root interception. Rice plants transpire 300 g of water to produce 1 g of dry matter (estimated from the data of SUGIMOTO, 1971). One gram contains about 3 mg of P and it is assumed that the soil solution reaches a concentration of 0.2 *ppm* P. If phosphorus is supplied to the plants through mass flow only, a rice plant should transpire 15 kg of water. Thus, it appears that diffusion and root interception are also playing an important role in the phosphorus uptake in rice plants. In a water culture experiment, TANAKA (1962) observed that when the capacity factor is sufficiently large, an extremely low concentration of P in the culture solution makes it possible for the rice plants to achieve normal growth and yield. OKAJIMA and IMAI (1973) measured the nutrient concentration in the soil solution of paddy fields and the nutrient uptake by rice plants, and concluded that the rate of mass flow contributing to the uptake of N, P and K was less than 70 %.

OLSEN and WATANABE (1963) showed that the rate of P uptake depends on the concentration of soluble P and the concentration gradient, the diffusion coefficient of P in soil and the capacity of the soil to replenish P removed by the plant, and each of these three factors varies mainly with the clay content of the soil or the soil texture. When P concentration in the soil solution is less than 0.2 *ppm*, the importance of diffusion in the soil-root media for the availability of P was emphasized.

GUNARY and SUTTON (1976) measured the log [P] ([P] is the P concentration in the 0.01 *M* $CaCl_2$ extract of a soil) as an intensity factor, E (18h) (the soil P exchangeable with ^{32}P after 18 hours of shaking in 0.01 *M* $CaCl_2$), E (14-day), L-value (the soil P exchangeable with ^{32}P within 12 weeks under pot experiment conditions) and citric soluble P (1 % citric acid extractable P) as capacity factors, P mobility index (the extent to which ^{32}P had penetrated 4-6 mm soil crumbs) as diffusion factor, resin P (P absorbed to anion exchange resin), percentage saturation (percentage E (18h) of the total P sorption) as intensity-capacity composite factors, and P uptake by ryegrass grown in pots. In soils of normal phosphate status, the capacity factor tended to show a higher correlation with the plant uptake and in enriched soils the intensity factor measured by log [P] and the composite factor resin P were important.

OLSEN and WATANABE (1970) assumed that the rate of P uptake could be calculated with the following equation: $Q = aB\,(Co - Cr)\,f\,(Dt/Ba^2)$ in which Q is the amount of P absorbed in time t, a is the root radius, B the soil buffer capacity (P in soil solution/labile P or resin P), D the diffusion coefficient of P, Co the initial P concentration in the soil solution, Cr the concentration at the root surface. Phosphorus uptake by maize roots in relation to time was measured in three calcareous soils and the validity of the equation was evaluated on the basis of the results. Thereafter based on the equation, the concentration of P in the soil solution required to maintain a certain rate of P uptake by the roots and the amount of P added with fertilizer were calculated. The higher the clay content of soil, the more phosphate should be added and with that amount the P concentration in the soil solution rose only slightly and all the soils regardless of their texture showed nearly the same values of $NaHCO_3$ extractable P (about 20 *ppm* of Olsen P) when the respective amount of P was added.

II Soil characteristics by soil group and ability to supply phosphorus

Soil samples

In Indonesia, phosphorus deficiency was reported in paddy fields with Red-Yellow Podzolic soils, Grumusols and Gray Hydromorphic soils. Collection of 12 soil samples representative of each soil group, of which phosphatic fertility for wetland rice was tested, was carried out in March, 1977. For comparison, 6 Japanese soil samples with varying degree of phosphorus fertility were collected from the Tohoku National Agricultural Experiment Station in Morioka, Iwate Prefectural Agricultural Experiment Station in Takizawa and the Okinawa Branch of the Tropical Agriculture Research Center in Ishigaki. Except for the Ishigaki soils, they were all plow soils or top soils.

The sampling locations of Indonesian soils are shown in Table 1 and Figure 1.

Analysis of physical and chemical properties, determination of available phosphorus with various extracting methods, and measurement of phosphorus uptake by rice seedlings grown in a beaker with soil were carried out on these soils to compare their characteristics and ability to supply phosphorus.

Analytical methods

After air-drying, the soil samples were made into fine soil (<2 mm) with a crushing/sieving machine (DIK-RD-2). No. 11 (PC) soil consisted of gravels (32.2 % air-dried weight) in addition to the fine soil. The whole quantity of each of the other soils was passed through a sieve to obtain fine soil.

Soil pH and electric conductivity (EC): Ten grams of fine soil was placed in a 50 ml beaker to which 50 ml of pure water was added. After the mixture was stirred, the electric conductance of the solution was measured with a EC meter (TOA, CM-6A with Electrode 200 PL), and the pH(H_2O) was measured with a pH meter (Horiba M-7 with combined electrode S-764-1). The pH(KCl) was measured on another 5 g of fine soil in 12.5 ml of *N* KCl.

Granulometric analysis: Ten grams of fine soil treated with hydrogen peroxide was sieved to separate the coarse sand fraction. The suspension was dispersed with 25 ml of 0.4 *N* sodium hexametaphosphate (calgon) and pure water was added to reach a volume of 500 ml. Clay + silt and silt fractions were determined on this suspension by the pipette method and after siphoning the remaining fraction was weighed as fine sand. Fractions determined without H_2O_2-treatment and calgon dispersion were referred to as water-dispersible silt or clay. (DOJOYOBUN SOKUTEIHO IINKAI, 1976, p. 65-71, abbr. DBS)

Three-phase distribution: A 100-ml metal cylinder filled with air-dried fine soil and mounted on an apparatus was dropped from 5 cm 5 times and the volume was adjusted for the determination of the volume weight of the soil. Then the soil in the cylinder was set in an apparatus (DAIKI, DIK-100) for the measurement of soil actual volume. From the determination of the volume weight, actual volume and moisture content, three-phase distribution and true density were calculated (DBS, 1976, p. 1-11).

Table 1. Soil samples*

No. 1	Tegineneng	(TG)	South Lampung, Lampung (Sumatra), Red-Yellow Podzolic Soil, alang-alang field, uncultivated
No. 2	Tamanbogo	(TB+)	Central Lampung, Lampung (Sumatra), Red-Yellow Podzolic soil, paddy-field, P fertilized in the past
No. 3	Tamanbogo	(TB-)	Central Lampung, Lampung (Sumatra), Red-Yellow Podzolic soil, newly opened paddy field, not fertilized
No. 4	Singamerta	(SM)	Serang, West Java, Yellow Podzolic/Gray Hydromorphic soil, flooded before transplanting
No. 5	Demak	(DM)	Demak, Central Java, Dark Gray Grumusol, tillering stage of rice
No. 6	Dempet	(DP)	Demak, Central Java, Dark Gray Grumusol, maturing stage of rice
No. 7	Ngale	(NG 1)	Ngawi, East Java, Dark Gray Grumusol, paddy field before cultivation
No. 8	Ngale	(NG u)	Ngawi, East Java, Dark Gray Grumusol, cassava field unfertilized
No. 9	Yogyakarta	(YG)	Grayish Brown Regosol (volcanic ash soil), paddy field before cultivation
No. 10	Jakenan	(JK)	Pati, Central Java, Gray Hydromorphic/Grayish Brown Planosol, before heading stage of rice
No. 11	Pacet	(PC)	Cianjur, West Java, Gray Regosol/Lithosol, flooded, uncropped field, covered with aquatic weed
No. 12	Muara	(MU)	Bogor, West Java, Reddish Brown Latosol, experiment station, paddy field before transplanting
No. 13	Kuriyagawa	(KR)	Morioka, Iwate, Andosol, Tohoku Natl. Agr. Exp. Station, upland field for NPK experiment, -P plot, after harvesting
No. 14	Takizawa	(TA-)	Iwate, Wet Andosol, Iwate Pref. Agr. Exp. Station, paddy field for NPK experiment, -P plot, after harvesting
No. 15	Takizawa	(TA+)	Same as above, NPK plot
No. 16	Kokaigawa	(KK)	Yatabe, Ibaraki, Gray Lowland soil, paddy field soil for pot experiment at TARC
No. 17	Maezato	(ME II)	Ishigaki, Okinawa, Dark Red soil**, upland field at Okinawa Branch of TARC. surface soil
No. 18	Maezato	(ME III)	Same as above, second horizon

* Table 1 includes the description of the soil samples in the following order: number/sampling location (abbreviation/kabupaten, state/soil mapping unit/note.

** This soil has been identified as Yellow soil recently.

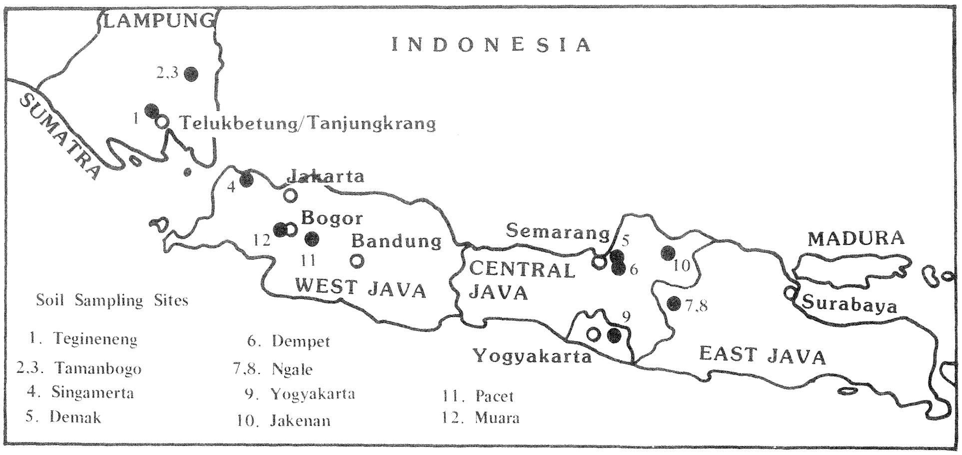

Fig. 1. Soil sampling sites in Java and Sumatra, Indonesia

Soil volume in water: Air-dried fine soil equivalent to 100 g of dry soil was placed in a 200-ml beaker and water was added. Height of the soil surface was recorded for each soil and the soil volume in water was calculated from the relation between the water volume and its height in the beaker.

Cation exchange capacity and exchangeable bases: Schollenberger's method (DOJOYOBUN SOKUTEIHO IINKAI, 1970, p. 34-38, abbr. DYB) was applied to 6 — 10 g of fine soil to determine the CEC. Exchangeable Ca, Mg, Na and K contents were determined on the ammonium acetate leachate by atomic absorption spectrography (Shimazu AA — 650).

Carbon: An air-dried soil sample of 500 mg that had been ground to pass through a 0.25 mm sieve was collected to determine the total carbon content by the Kosaka-Honda-Iseki's method (DYB, p. 127-134) and the results were referred to as organic carbon contents except for Grumusols. Samples of the four Grumusols were treated with sulfuric-ferrous sulfate solution to remove the carbon dioxide before determining the organic carbon content. Total carbon — organic carbon = inorganic carbon.

Nitrogen: A sample of 2.00 g of fine soil was digested in sulfuric acid with a mixture of potassium sulfate and cupric sulfate (9 : 1), and NH_3 in the solution was distilled into 4 % boric acid and titrated with *N*/50 sulfuric acid.

Soluble aluminum: A sample of 100 g of fine soil was extracted with 40 ml of *N* sodium acetate buffer solution pH 4.0 at 30°C for 3 hours. Al in the extract was determined by the aluminon method (DYB, p. 94-104).

Free iron oxides: Free iron in a sample of 0.5 g of fine soil was determined by the dithionite-EDTA method (ASAMI and KUMADA, 1959).

Olsen-EDTA solution extractable iron: The Olsen-EDTA method will be described in the next chapter. Iron extracted with the Olsen-EDTA solution from an anaerobically incubated soil was determined colorimetrically according to the Asami-Kumada method. (Olsen-EDTA iron/Free iron) × 100 = Iron mobility (%). The iron mobility indicates the rate of soluble iron under submerged incubation to the iron soluble through chemical reduction.

Clay minerals: Clay mineral composition was determined on the 12 representative soil samples by Dr. Kazuo ABE and Dr. Masatomo ARAAKE at the National Institute of Agricultural Sciences. They found that since the soils contained a large amount of X-ray amorphous fraction, it was necessary to apply two or three extractants to the soils. In the following discussion, the data in the report of Dr. Nobuo KOSUGE who belonged to the team of the Japan-Indonesia Joint Food Crop Research Program will be cited, in which he determined the composition of clay minerals and primary minerals in the fine sand fraction of the soils.

Total phosphorus: A sample of 1 g of air-dried fine soil was digested with perchloric acid after treatment with nitric acid. Phosphate in the mixture was determined colorimetrically by the ammonium metavanadate method (JACKSON, 1962).

Phosphate sorption coefficient: Phosphate sorption coefficient was measured by an ordinary method, whereby one part of soil is placed in two parts of 2.5 % $(NH_4)_2HPO_4$ solution (DYB, p. 251-253). Phosphorus was determined by the ammonium metavanadate method. Phosphate sorbing capacity was also measured in the 0.25 % and 0.025% ammonium phosphate solutions by using the same technique as that for the phosphate sorption coefficient, but phosphorus was determined by the ascorbic acid reducing molybdenum-blue method, because of its higher sensitivity, persistence of blue color and convenient preparation of the reagent mixture for the development of the color from the sulfomolybdic solution and ascorbic acid crystal. This method, however, could not be applied to the sample solution containing a large amount of Cl.

Fractionation of soluble inorganic phosphates: Using the method described by EGAWA and SEKIYA (DYB, p. 238-239), soil phosphorus was fractionated into Ca-P (2.5 % acetic acid soluble), Al-P (N NH_4F soluble) and Fe-P (0.1 N NaOH soluble). Phosphorus in Ca-P and Al-P fractions was determined by the chloromolybdic method and that in Fe-P by the sulfomolybdic method, and stannous chloride was used as reducing agent in both cases.

Available phosphate: Available phosphate was measured by the following methods.

Phosphate uptake by rice seedlings

A solution of urea and K_2SO_4 equivalent to 10 mg of N and K_2O per beaker was added to 100 g of soil (oven dry basis) placed in a 200-ml beaker. After incubation for 2 weeks at 35°C under submerged conditions, the soil in the beaker was covered with 1 cm of washed sea-sand and sown with 40 soaked rice seeds. The beaker was placed in a growth cabinet with electric illumination at 21°C. Temperature in the cabinet was raised up to 27°C as rice grew. In the course of rice growth, 20 mg and 10 mg N of NH_4NO_3 solution respectively were added to the beaker twice to eliminate N deficiency. After 40 days, the aerial parts of rice plants were collected and total phosphorus uptake was determined. To estimate P uptake derived from the soil, the amount of P in rice plants grown on sand-solution beaker was subtracted from the total P uptake.

Soil testing methods

Bray II method

Two grams of air-dried fine soil was extracted with 20 ml of Bray No. 2 solution, 0.03 *N* NH_4F-0.1 *N* HCl, in shaking by hand for 40 seconds. When the method was applied to a submerged incubated soil, as will be described later, a 1.6 times concentrated solution was prepared to keep the same extracting conditions as in air-dried soil.

Olsen method

A sample of 2.5 g of air-dried fine soil was extracted with 50 ml of 0.5 *M* $NaHCO_3$ solution adjusted to pH 8.5 by NaOH in shaking for 30 minutes. For extracting the submerged incubated soil, a 1.23 times concentrated solution was prepared.

Resin method

Strongly basic anion-exchange resin Doulite A-101 D was prepared to obtain a size above 30 mesh. A mixture of 1 g soil passed through 0.25 mm sieve and 2 g of wet regenerated resin, suspended in 100 ml of water, was shaken for 16 hours, then sieved through a nylon net of 30 mesh (NGG 32) to collect the resin. The phosphate sorbed by the resin was recovered by leaching with 40 ml of *N* Na_2SO_4 solution and determined colorimetrically. The amount of water to be added to the mixture had little effect on the extraction of phosphate.

Equilibrated aqueous solution method

A sample of 6 g of air-dried fine soil was placed in a 25-ml test tube with a stopper and the tube filled with water was allowed to stand in an inverted position for incubation at 35°C for 30 days. It was shaken every few days to eliminate the oxidized parts. In the morning of the determination, the tube was straightened after shaking and when the suspension was cleared 10 ml of the supernatant solution was pipetted into a beaker containing a few ml of diluted sulfuric acid. After filtering, the acid solution was used for phosphate determination. (This anaerobic incubation method using test tube with stopper was presented by UWASAWA and UCHIDA of Tohoku National Agricultural Experiment Station at the Annual Meeting of the Soc. Sci. Soil and Manure, Japan, 1977).

Bray II, Olsen and Resin method for submerged soil

A sample of 4 g of air-dried fine soil was placed in a test tube (1.5 × 16.5 cm) containing 15 ml of urea and K_2SO_4 solution equivalent to 15 mg of N and K per 100 g of soil. The test tube was tightly covered with parafilm and incubated at 35°C. Bray II extraction was carried out after 21 days and Olsen extraction after 26 days of incubation. As stated previously, a somewhat concentrated extracting solution was used for submerged soils.

One gram of air-dried fine soil passed through a 0.25 mm sieve was placed in a test tube containing 13 ml of water. The test tube covered with parafilm was incubated at 35°C and phosphate in the soil was extracted with resin after 43 days.

Colorimetry of phosphate

Phosphate in the extractant and equilibrated solution was determined by the ascorbic acid reducing molybdenum-blue method (JOHN, 1970). Before color development an aliquot of Olsen's extractant was neutralized by adding dilute sulfuric acid until the disappearance of CO_2 gas bubbles.

Results

Physical and chemical properties of the soils (Tables 2-5)

Electric conductivity (EC)

Pacet soil (No. 11) had an extraordinarily high EC and low pH. As the soil had developed on the mud-flow of pyroclasts originating from the crater of a volcano, this finding can be explained on the basis of a high sulfuric acid content. Four Grumusols, Nos. 5-8, also showed comparatively high EC values.

Soil pH

Pacet soil had the lowest pH value of 3.4. Four Grumusols and a Regosol (No. 9) derived from volcanic ashes of Mt. Merapi were neutral or basic. In general, pH(H_2O) values were higher than the pH(KCl) values.

Particle size distribution

Red-Yellow Podzolic soils, Nos. 1, 2 and 3, had a large sand fraction consisting chiefly of quartz sand. They were not so low in clay content, but the dispersion ratios of silt and clay of these soils were somewhat higher. Grumusols had very high clay contents and the silt + clay contents exceeded 90 %. Rather low dispersion ratios of both fractions suggested the formation of aggregates from finer soil particles. The Reddish Brown Latosol (No. 12), containing 67 % clay fraction—thus being classified as heavy clay (HC) had a very low dispersion ratio, which was due to the aggregation of clay-silt particles

Table 2. Physical and chemical properties of the soil samples (I)

Soil No.		EC (1:5) µmho/cm	pH (H_2O) 1:5	pH (KCl) 1:2.5	Particle size analysis (%) Coarse sand	Fine sand	Silt	Clay	Soil* texture
1	TG	18	6.3	5.2	28.4	34.7	16.8	20.1	SCL
2	TB+	13	5.5	4.1	18.6	33.3	10.5	37.6	LiC
3	TB-	11	5.7	4.2	15.2	30.6	11.0	43.2	LiC
4	SM	47	5.3	4.0	2.9	16.2	34.2	46.9	HC
5	DM	175	8.4	7.0	2.6	5.8	10.4	81.2	HC
6	DP	80	8.3	7.0	1.0	1.4	13.7	83.9	HC
7	NG 1	84	8.0	6.6	1.6	6.5	8.9	83.0	HC
8	NG u	55	6.9	5.3	1.2	4.9	9.5	84.3	HC
9	YG	37	7.1	5.6	43.0	39.3	9.6	8.0	SL
10	JK	21	5.4	3.9	1.0	55.9	33.7	9.4	FSL
11	PC	668	3.7	3.4	39.8**	33.0	11.5	15.8	SCL
12	MU	19	5.7	4.5	3.4	10.2	19.7	66.6	HC
13	KR	65	5.4	4.8	26.0	35.0	35.9	3.1	L
14	TA-	27	6.3	5.7	32.1	38.0	27.7	2.2	SL
15	TA+	24	5.9	5.2	31.3	34.6	32.2	1.9	SL
16	KK	79	5.5	4.6	10.6	35.9	21.7	31.8	LiC
17	MEII	19	4.9	3.9	43.4	19.7	14.7	22.1	SCL
18	MEIII	35	4.5	3.9	47.0	17.1	12.5	23.4	SCL

Since No. 11 soil contained 30.2 % gravel fraction before 2 mm-sieving, it should be referred to as "sandy clay loam" with profuse small gravels (pumice).

* Soil texture was expresed accordingly to the International Scheme

Table 3. Physical and chemical properties of the soil samples (II)

Soil No.	Water dispersible Silt +clay	Water dispersible Clay (%)	Dispersibility Silt +clay	Dispersibility Clay (%)*	Bulk density **	Three-phase distribution Solid (ml/100 ml)	Three-phase distribution Liquid (ml/100 ml)	Three-phase distribution Gas (ml/100 ml)	Particle density	Volume in water ml***
1 TG	12.4	1.3	34	6	127	46	2	52	2.75	77
2 TB+	10.9	1.2	23	3	112	40	3	57	2.79	95
3 TB-	12.9	1.7	24	4	109	39	4	57	2.79	95
4 SM	16.5	1.1	20	2	92	34	10	56	2.69	116
5 DM	15.9	3.6	17	5	101	37	13	50	2.74	122
6 DP	13.9	4.3	14	5	99	37	13	50	2.66	125
7 NG 1	18.8	7.7	21	9	90	35	14	51	2.59	152
8 NG u	16.8	8.3	18	10	89	35	13	52	2.58	152
9 YG	3.7	0.8	21	10	128	46	3	51	2.80	74
10 JK	25.2	0.8	59	8	134	50	1	49	2.68	71
11 PC	2.0	1.1	5	7	83	30	6	64	2.73	110
12 MU	6.3	1.2	7	2	93	32	11	57	2.92	104
13 KR	19.4	0.7	50	22	66	25	11	64	2.66	131
14 TA-	14.4	0.6	48	29	71	26	10	64	2.76	131
15 TA+	15.3	0.8	45	42	70	26	8	66	2.72	134
16 KK	15.0	2.3	28	7	107	39	5	56	2.75	107
17 MEII	16.6	4.2	45	19	126	46	3	51	2.75	68
18 MEIII	4.2	0.5	12	2	128	46	3	51	2.79	74

* Dispersibility: (water dispersible silt and clay/calgon dispersible silt and clay after H_2O_2 treatment) × 100 (%), (water dispersible clay/calgon dispersible clay after H_2O_2 treatment) × 100 (%)

** Bulk density: dry weight of 100 ml of air-dried soil

*** Volume of 100 g of dry soil in water

Table 4. Physical and chemical properties of the soil samples (III)

Soil No.	Total C %	Inorganic C %	Total N %	C/N *	Soluble Al mg/100g	Free Fe %	Olsen-EDTA-Fe ppm	Iron mobility % **
1 TG	1.32		0.11	13	11	1.9	770	4.1
2 TB-	1.42		0.10	14	49	2.0	2320	11.6
3 TB+	1.58		0.13	12	52	3.2	3060	9.6
4 SM	1.79		0.15	12	85	2.2	4020	18.3
5 DM	1.37	0.61	0.14	5	53	2.0	1200	6.0
6 DP	1.59	0.16	0.16	9	48	1.6	420	2.6
7 NG 1	1.74	0.02	0.10	17	54	0.9	870	9.7
8 NG u	1.55	0.03	0.10	15	30	0.8	300	3.8
9 YG	0.78		0.08	10	22	1.4	620	4.4
10 JK	0.49		0.04	12	15	0.4	730	18.3
11 PC	1.95		0.16	13	518	2.0	6660	33.3
12 MU	1.59		0.16	10	47	6.3	1560	2.5
13 KR	6.97		0.47	15	558	3.8	1050	2.8
14 TA-	5.39		0.33	16	545	3.4	1190	3.5
15 TA+	5.19		0.40	13	471	3.2	2800	8.8
16 KK	1.62		0.13	13	51	3.3	1180	3.6
17 MEII	0.77		0.07	11	40	1.7	970	5.7
18 MEIII	0.20		0.03	7	44	1.8	120	0.7

* The C/N ratios for Nos. 5-8 Grumusols were calculated in terms of Organic C (Total C — Inorganic C).

** Iron mobility: (Olsen-EDTA extractable Fe in submerged incubated soil/Free Fe in air-dried soil) × 100 (%)

Table 5. Physical and chemical properties of the soil samples (IV)

Soil No.		CEC	Ca	— meq/100 g — Exchangeable Mg	Na	K	Sum	Base saturation degree (%)	CEC/clay meq/g
1	TG	8.1	4.8	1.1	0.02	0.31	6.2	76	0.40
2	TB+	8.2	1.8	0.6	0.06	0.18	2.7	32	0.22
3	TB-	8.6	1.8	0.9	0.07	0.26	3.1	36	0.20
4	SM	30.1	16.4	5.6	0.26	0.43	22.7	75	0.64
5	DM	51.4	69.6	7.7	0.86	0.74	78.9	154	0.63
6	DP	61.2	77.9	7.4	0.34	0.88	86.6	142	0.73
7	NG 1	78.2	65.0	17.2	0.51	0.31	83.0	106	0.94
8	NG u	79.9	61.1	16.5	0.20	0.29	78.1	98	0.95
9	YG	9.6	5.5	2.4	0.13	0.31	8.4	87	1.20
10	JK	3.8	2.0	0.3	0.05	0.09	2.4	63	0.40
11	PC	18.6	8.0	2.3	0.52	0.59	11.5	62	1.17
12	MU	17.1	7.1	2.0	0.10	0.36	9.6	56	0.26
13	KR	27.6	6.2	0.3	0.05	0.27	6.8	25	8.90
14	TA-	24.9	11.5	1.3	0.12	0.13	13.0	52	11.32
15	TA+	26.1	6.9	0.7	0.16	0.08	7.9	30	13.74
16	KK	16.0	8.6	1.7	0.20	0.27	10.8	68	0.50
17	MEII	6.9	0.3	0.3	0.06	0.26	0.9	13	0.26
18	MEIII	5.7	0.7	0.4	0.08	0.16	1.4	22	0.22

with iron oxides as cementing materials. Low dispersion ratio of strongly acid Pacet soil (No. 11) might be caused by the aggregation with iron and aluminum oxides which were abundant in the soil. Jakenan soil (No. 10), the strongly leached Planosol, containing about 90 % of fine sand-silt fraction, showed the highest dispersion ratio of the silt-clay fraction among the soils studied. This is due to its extremely low contents of clay, Ca and Fe, which are conducive to aggregation. Three Andosols from Iwate (Nos. 13 — 15) had a low clay content and high dispersion ratios. Surface soil of Ishigaki (No. 17, ME II) also showed a high dispersion ratio, suggesting the migration of base, iron and clay to the subsoil.

Three-phase distribution, and bulk and particle density

Bulk density was high in No. 10 Planosol>No. 9 Regosol>No. 1 Podzolic soil and the order of magnitude was in agreement with that of their solid ratios. The lowest dispersion ratio, the low solid ratio, the low bulk density and the highest particle density of No. 12 Latosol suggested that the soil was rich in iron. Both No. 11 Regosol which had a high aggregation ratio and No. 13 — 15 Andosols which had a high organic matter content had small bulk densities. Liquid ratio indicated the moisture content of air-dried fine soil. Nos. 5-8 Grumusols which contained much clay had high liquid ratios and No. 10 Planosol containing little clay had a low liquid ratio. Thus, the moisture content can be assumed to be nearly proportional to the clay content. However, ratios of moisture content/clay content which were high in Nos. 9 and 11 Regosols derived from volcanic ashes suggest that soil particles larger than clay have active internal surfaces in addition to outer surfaces. Similarly, moisture/clay ratios of Nos. 13-15 Andosols from Iwate were ten times higher than those of the above soils. This also indicates that soils of volcanic ash origin are porous and highly humic, hence have a high water holding capacity.

Soil volume in water

Nos. 5-7 Grumusols, Nos. 13-15 Andosols, No. 4 Hydormorphic soil, No. 11 Regosol and No. 12 Latosol, which have high liquid ratio, have also a high volume in water. Thus, volume in water may relate with clay and humus contents. However, the humus and clay contents of No. 11 Regosol were not high enough to account for the high volume in water recorded. This soil had the lowest bulk density and dispersion ratio among the soils studied except for Andosols. This indicates its unique aggregation mechanism.

Total and inorganic carbon, and total nitrogen

Nos. 5-8 Grumusols with a dark gray color did not have a high total carbon content, suggesting that the presence of a dark color does not imply high humus content. However, Nos. 5 and 6, and Nos. 7 and 8 soils were collected in different locations and the color of the former two soils was slightly lighter than that of the other two. This relation corresponded with the organic carbon contents of the soils. Carbon-nitrogen ratios and some other properties were quite different between both groups of soils. These findings may be related to the fact that Nos. 5 and 6 were younger soils and Nos. 7 and 8 old ones. Except for the subsoil of No. 18 sample, a Dark Red soil from Ishigaki, No. 10 Planosol showed the lowest carbon and nitrogen contents. In general, humus content corresponded with the clay content, while the very high total carbon content of Andosols with low clay content suggested that the form of humus in Andosols differed from that in other soils.

Soluble aluminum, free iron oxide and iron mobility

No. 10 Planosol showed the lowest contents of soluble aluminum in an acetate buffer solution at pH 4. No. 11 Regosol with a strongly acid volcanic ash origin and Nos. 13 — 15 Andosols had markedly higher contents of soluble aluminum. Free iron content was highest in No. 12 Latosol and lowest in No. 10 Planosol. This could be predicted from the color of those soils. However, Nos. 1-3 Red-Yellow Podzolic soils with a red color had a lower free iron content than No. 16 Gray Lowland soil, indicating that free iron is not the sole factor to determine soil color. Free iron content was high in young Grumusols of Nos. 5 and 6 samples and low in old Grumusols of Nos. 7 and 8 samples.

Iron mobility is the ratio of the iron dissolved by microbiological reduction under submerged conditions to the free iron dissolved by hydrosulfite (dithionite) reduction. The highest mobility was observed in No. 11 Regosol followed by No. 10 Planosol and No. 4 Hydromorphic soil.

Cation exchange capacity (CEC) and exchangeable bases

High CEC of Nos. 5-8 Grumusols can be ascribed to their very high contents of clay with a high CEC per gram of clay, whereas the low CEC of No. 12 Latosol with 67 % clay indicates that its clay mineral composition may be different from that of Grumusols. Values of CEC/g of clay were high in No. 9 and No. 11 Regosols of volcanic ash origin, suggesting that soil particles larger than clay have inner surfaces active as CEC, as discussed in the section dealing with the moisture retention capacity. In particular, the high CEC/clay ratios of Nos. 13-15 Andosols can be explained by the contribution of humus and porosity of soil particles to CEC.

For most of the soils, contents of exchangeable bases were in the order of Ca>Mg>K>Na, while for Nos. 5 and 7 Na>K. Nos. 5-8 Grumusols had an extremely high content of exchangeable Ca and a base saturation degree of more than 100 %. In these four soils, CEC and exchangeable Mg were in the order of Nos. 5 and 6>Nos. 7 and

8, whereas exchangeable Ca, K and base saturation degree were in the order of Nos. 5 and 6>Nos. 7 and 8.

Table 6. Clay mineral composition of the soil samples determined by ARAAKE and ABE

	No. Soil	Amor.	Kt	Kn	Mt	Al-Vr	Vr	14 Å	Int	Mica	Qz
1 TG	R. Y. Podzolic	±	++++			±~+					-~±
2 TB+	R. Y. Podzolic		++++					±			-~+
4 SM	G. Hydromorph.			+	++++					-~±	±
6 DP	D. G. Grumusol			+	++++						±
7 NG1	D. G. Grumusol				++++						
9 YG	Reg. (volcanic)	++++									
10 JK	Planosol			+~++	+++						±
11 PC	Reg. (volcanic)	++++		-~±						-~±	
12 MU	R. B. Latosol	+++		+~++							
14 TA-	Andosol	++++									
16 KK	Gray Lowland	±		++~+++		+~++			+~++	±	±
17 MEII	Dark Red	-~±		++		+	+		±	++	+

++++>70 %, +++ 60-50 %, ++ 40-30 %, + about 10 %, ± about 5 %

Amor.: Amorphous materials to X-ray including Allophane Kt: Kaolinite Kn: 7 Å Kaolinite minerals (Kaolinite or Meta-halloysite) Mt: Smectite (Montmorillonite minerals) Al-Vr: Al interlayer Vermiculite Vr: Vermiculite 14 Å: 14 Å minerals (Mt, Vr, or Chlorite etc.) Int: Intergradational minerals (14 Å-14 Å or 14 Å-10 Å) Mica: Mica clay minerals Qz: Quartz

Analytical methods: WADA, K. 1966. Qualitative and quantitative determination of clay minerals. J. Sci. Soil Manure, Japan, 37 (1) 9-17 (in Japanese)

Table 7. Examination of "amorphous materials to X-ray" by ARAAKE and ABE (percentage of weight loss after treatment to initial weight)

Soil No.			NH_4-oxalate	CDB-$N/2$ NaOH	CDB	Tamm's (Fe_2O_3)
			%	%	%	%
1	TG	Red-Yellow Podzolic	5.3			
2	TB+	Red-Yellow Podzolic	2.2			
4	SM	Gray Hydromorphic	2.9			1.87
6	DP	Dark Gray Grumusol	0.5			
7	NG1	Dark Gray Grumusol	tr.			
9	YG	Regosol (volcanic)	10.1	37.4	9.3	
10	JK	Planosol	tr.			
11	PC	Regosol (volcanic)	10.5	43.0	11.7	1.69
12	MU	Reddish Br. Latosol	4.3	40.9	17.5	
14	TA-	Andosol	79.3	78.3	n.d.	
16	KK	Gray Lowland soil	6.5			
17	MEII	Dark Red soil	3.9			

NH_4-oxalate: Schwartman method. Shaking a soil with pH 3.0 NH_4-oxalate solution for 4 hrs in a dark place. Weight loss is considered to correspond to the amount of allophane.

CDB-$N/2$ NaOH: HASHIMOTO & JACKSON method: After CDB (0.3 M Na-citrate-$Na_2S_2O_4$-1 M $NaHCO_3$) treatment (MEHRA & JACKSON), a soil is boiled in a $N/2$ NaOH solution for 2.5 minutes, and the last treatment is repeated once more. The weight loss corresponds to the amount of allophane, free iron oxides, alumina and silica.

Tamm's reagent: Na-oxalate-Oxalic acid, pH 3.20. This reagent is assumed to dissolve very fine ferric oxide particles.

Clay minerals (Tables 6 and 7)

KITAGAWA, KYUMA and KAWAGUCHI (1973) reported that three Andosols from Java, which are considered to be young volcanogeneous soils, contained abundant amounts of allophane and small amounts of halloysite, gibbsite and imogolite in their clay mineral composition. Also α-cristobalite was frequently observed unlike quartz, whereas a Reddish Brown Latosol in Bogor, which was considered to be an old volcanogeneous soil, had a clay mineral composition with a predominance of halloysite.

The presence of large quantities of kaolinite in Nos. 1 and 2 Red-Yellow Podzolic soils indicates that they were tropical red-colored soils produced through laterization. Quartz was found in the clay fraction of those soils and 80 % of the coarse and fine sand fractions consisted of quartz.

No. 4 Hydromorphic soil which contained considerable amounts of montmorillonite and a little kaolinite, mica and quartz, showed a complex composition of parent materials typical of that of Alluvial soil. Quartz was abundant in the fine sand fraction.

High montmorillonite content in Grumusols could account for their high CEC and rate of CEC per gram of clay. Some amount of kaolinite was mixed in the clay fraction of No. 6 soil. Therefore, it can be assumed that Nos. 5 and 6 soils of the coastal plain differed from Nos. 7 and 8 soils of the inland basin in their physical and chemical properties as well as in kaolinite contamination, though both of them can be designated as Dark Gray Grumusols. Primary mineral composition of the former soils was as follows: feldspar≫amphibole>limonite and of the latter soils feldspar≫quartz>amphibole.

It is interesting to note that No. 10 Planosol with a low CEC contained also montmorillonite in the 9 % clay fraction, because the soil is distributed on the northern slopes of the North Limestone Range (Pegunungan Kapur Utara) which supplied parent materials to Nos. 5 and 6 Grumusols in the coastal plain, although No. 10 soil is highly leached and deficient in most of the nutrient elements. The soil contains kaolinite and quartz and out of 56 % of the fine sand present in the soil 75 % consisted of quartz. Thus, practically all the soil particles can be considered to represent the quartz fraction. The soil was once named "podzolized lateritic soil" (DAMES, 1955). "Podzol" may account for its low clay and high quartz content and "lateritic" may refer to its pink color indicating that the soil belongs to one of the tropical red-colored soils.

Nos. 9 and 11 Regosols and No. 14 Andosol, derived from volcanic ash, contained large amounts of amorphous or uncrystallized materials. No. 12 Latosol, which was rather rich in amorphous materials, also originated from mud-flow deposits of andesitic tuff. Amorphous materials in the soils were analysed using various solvents. Weight-loss after ammonium-oxalate treatment, which was assumed to dissolve mainly allophane, was 80 % for No. 14 Andosol, whereas it was 10 % for Nos. 9 and 11 soils, suggesting that these relatively new volcanic ash soils in Java did not have a high allophane content. Weight-loss after CDB-NaOH treatment was similar to that consecutive to ammonium-oxalate treatment for Andosol, while it amounted to 40 % for Nos. 9 and 11 soils, suggesting that the amorphous materials in these soils consisted of free iron oxide, alumina and silica.

The physical and chemical properties and the presence of kaolinite minerals in No. 12 Reddish Brown Latosol seemed to indicate that the soil was a product of laterization.

No. 16 soil is an Alluvial soil from Ibaraki and No. 17 a colluvial soil from Ishigaki, Okinawa. Unweathered primary minerals could be seen with the naked eye in both soils. They had a clay mineral composition which was more complex than that of tropical soils.

Table 8. Soil properties related to phosphate fertility*

	Soil No.	mg P_2O_5/100 g Total -P	P-sorp. coef.	Inorganic P fraction* ppm P Ca-P	Al-P	Fe-P	Sol. P/ Total P %	P uptake by rice** mg P/100 g
1	TG	62	440	44	26	24	35	0.46
2	TB+	82	620	38	73	58	47	2.25
3	TB-	78	660	36	36	43	34	0.53
4	SM	114	1500	56	49	105	42	6.26
5	DM	153	2530	66	112	101	42	2.40
6	DP	178	2240	105	113	66	37	1.10
7	NG 1	128	2020	43	49	36	23	3.21
8	NG u	114	1950	37	19	9	13	1.39
9	YG	246	440	411	259	51	67	3.16
10	JK	39	150	52	34	10	57	2.50
11	PC	139	1280	27	63	114	34	5.85
12	MU	337	1300	18	68	186	19	2.06
13	KR	262	2710	32	104	11	13	0.25
14	TA-	248	2540	20	133	18	16	0.26
15	TA+	584	2480	42	823	148	40	3.35
16	KK	212	810	25	87	147	28	4.28
17	MEII	161	370	24	74	180	40	3.16
18	MEIII	180	420	18	58	239	40	0.48

* Inorganic soluble phosphorus fractionation by Egawa and Sekiya method
** Phosphorus uptake by rice seedlings using 100 g of soil

Total phosphorus and inorganic fraction of phosphorus (Table 8)

Total phosphorus contents ranging from 39 to 584 mg P_2O_5/100 g, were the lowest in No. 10 Planosol which is a highly leached soil, and the highest in No. 15 Andosol from a paddy field which was fertilized annually with N, P and K in Iwate Agr. Exp. Station. The content was low in Nos. 1, 2 and 3 Red-Yellow Podzolic soils and high in No. 9 Regosol and No. 12 Latosol.

Ca-P was high in No. 6 Grumusol and No. 9 Regosol. It is noteworthy that Grumusols contained large amounts of exchangeable Ca, although Ca-P was not necessarily dominant in the inorganic soluble phosphorus. DJOKOSUDARDJO (1974) observed that some Alluvial soils in Java had a Ca-P content more than 10 times higher than that of the Grumusols of the same area. No. 9 Regosol is a volcanic ash soil originating from Mt. Merapi, an active volcano. BAAK (1949) reported that the ash contained apatite particles and the ratio of hydrochloric or citric acid soluble phosphate to total phosphate in the ash was higher than that of ashes from Mt. Semeru and Mt. Kelud. When No. 7 Grumusol from a paddy field was compared with No. 8 Grumusol from an upland field, the former had a higher ratio of solubility of inorganic phosphorus to total phosphorus and a lower ratio of Ca-P to total soluble phosphorus. The same relations were observed between No. 14 Andosol from a paddy field and No. 13 Andosol from an upland field.

Phosphate sorption coefficient (Table 8)

Phosphate sorption coefficients were very high in Andosols (Nos. 13-14) and high in Grumusols followed by No. 4 Hydromorphic soil, No. 12 Latosol and No. 11 Regosol. The lowest value was observed in No. 10 Planosol. Sandy loam, No. 9 Regosol derived from basic volcanic ash and Nos. 1-3 Red-Yellow Podzolic soils had low coefficients.

In addition to the 2.5 % ammonium phosphate solution, which is commonly used as a bathing solution for determining the coefficient, a solution containing 0.25 and 0.025 %

of ammonium phosphate was used to determine the amount of sorbed phosphorus per gram of soil and the concentration of the remaining phosphorus in the equilibrated solution. The results are presented in Figure 3. Low initial concentration of phosphorus in the solution resulted in a low amount of sorption, while decreasing rates of sorption varied with the soils.

Table 9. Soil test values obtained by various methods (*ppm* P of dry soil)

Soil No.		Equil. solution -P*	Anion exchange resin-P A	Anion exchange resin-P B	Bray II-P A	Bray II-P B	Olsen-P A	Olsen-P B	Olsen-EDTA-P B
1	TG	0.11	3.0	2.1	3.6	6.4	4.4	3.8	8.4
2	TB+	0.07	1.7	2.3	9.9	27.9	9.1	7.4	31.9
3	TB-	0.05	1.3	0.5	2.6	8.4	3.1	2.1	10.2
4	SM	0.36	2.6	3.8	11.2	94.1	10.2	11.4	78.4
5	DM	0.07	5.3	10.3	9.7	31.8	7.5	7.9	23.5
6	DP	0.05	5.5	11.2	58.5	67.2	7.1	5.2	25.6
7	NG 1	0.11	9.6	19.4	27.1	34.5	14.0	13.3	39.2
8	NG u	0.06	2.6	3.0	12.0	11.0	3.8	6.0	13.3
9	YG	0.64	8.8	8.6	78.8	156.6	9.4	9.6	30.9
10	JK	1.22	3.1	2.3	21.4	41.3	8.1	6.4	27.8
11	PC	0.42	0.8	0.1	19.6	60.2	14.0	7.9	76.5
12	MU	0.06	3.1	8.0	9.1	11.9	16.7	14.1	38.9
13	KR	0.07	0.9	0.05	9.3	8.4	2.7	2.8	12.3
14	TA-	0.05	1.1	0.1	10.4	7.2	3.1	2.8	10.5
15	TA+	0.11	3.7	6.7	21.5	20.7	55.8	27.6	127.6
16	KK	0.10	4.7	7.8	28.6	35.7	20.1	16.9	40.5
17	ME II	0.28	2.2	4.4	40.4	43.4	17.5	12.3	47.2
18	ME III	0.03	1.3	0.7	24.2	21.5	12.0	7.4	31.3

* *ppm* P of equilibrated solution
A: air-dried soil B: submerged incubated soil

Available phosphorus (Tables 8 and 9)

Phosphorus uptake by rice seedlings

When No. 4 Hydromorphic soil and No. 11 a strongly acid Regosol were submerged, the dissolved and liberated iron induced the formation of an iron-rust film on the surface of water and rice seeds, and the growth of germinated seeds was delayed. After the coleoptiles or young leaves emerged from the water surface, the plants grew rapidly and showed a high uptake of phosphorus. On Nos. 5-8 Grumusols and No. 9 Regosol, which had a high pH under air-dried conditions, rice growth was normal just after germination, but later it became unsatisfactory and resulted in a low phosphorus uptake. It could be concluded that regardless of rice growth at and after germination, phosphorus uptake by rice seedlings reflected the amount of phosphorus available in soil.

Phosphorus concentration in equilibrated aqueous solution

Under submerged conditions, phosphorus concentration in the aqueous solution of reduced soil was the highest in No. 10 Planosol which had the lowest total phosphorus content. Since the solubility was less than 1 % in this soil, there was no correlation between the amount of total phosphorus and water soluble phosphorus. Water soluble phosphorus was less than 0.1 *ppm* P in the solution for most of the soils and when some iron-rust appeared in the supernatant solution in the incubation tube, as an indication of air-leakage, no phosphorus was detected in the solution.

Phosphorus extracted by anion exchange resin method

In general, the P values were high for neutral and basic soils and increased furthermore for Grumusols after submerged incubation. For No. 11 Regosol, No. 13 and 14 Andosols, the values decreased after submerged incubation.

Phosphorus extracted by Bray II method

No. 9 Regosol showed the highest value and the value was doubled after submerged incubation. Submerged incubation increased the values for most of the soils, but decreased them slightly for Nos. 13 and 14 Andosols.

Phosphorus extracted by Olsen and Olsen-EDTA method

Olsen-P values of air-dried soils were nearly the same as Bray II-P values, while for the soils rich in Ca-P, Bray II-P values were very much higher. In contrast, No. 15 Andosol had by far the highest Olsen-P value. Submerged incubation decreased the values for many soils and increased them for a few soils.

Olsen-EDTA extraction was applied only for submerged incubated soils and the P values were more than twice as high as the Olsen-P values of air-dried soils.

Discussion

1. Physical and chemical characteristics of each soil group

The physical and chemical properties of the soil samples have been analysed to characterize each soil group.

Red-Yellow Podzolic soils (No. 1 TG, No. 2 TB+, No. 3 TB-):

These soils contained a large amount of coarse and fine sand fractions and their silt-clay fractions showed a high water dispersibility. They were acid, low in total nitrogen in relation to total carbon, had a slightly high C/N ratio, and were rather high in free iron oxides and bulk density, but they had a low CEC and small amount of exchangeable bases. Both the total phosphorus contents and the phosphate sorption coefficients were rather low and the iron mobility slightly high. To sum up, these soils were formed from silicic, low base materials under the tropical rain forest climate, or in other words, under the weathering process of laterization. However, because of lack in iron and bases, their clay fractions were insufficiently aggregated and had a relatively high dispersibility.

Yellow Podzolic/Gray Hydromorphic soil (No. 4 SM):

According to the analytical results of the Gray Hydromorphic/ Grayish Brown Planosol collected at the Singamerta Substation by KAWAGUCHI and KYUMA (unpublished) the soil had a CEC of 11 meq/100 g, exchangeable bases of 7 meq/100 g, soil texture of LC -CL, total phosphorus of 74 mg P_2O_5/100 g, Bray II-P of 22 (air-dried soil), 66 *ppm* P (submerged incubated soil), and phosphate sorption coefficient of 409, while No. 4 soil collected in a paddy field 500 m west of the Substation differed from the above soil in clay content and related properties and had a CEC of 30 meq/100 g, exchangeable bases of 22 meq/100 g, texture of HC, total phosphorus of 114 mg P_2O_5/100 g, Bray II-P of 11 (air-dried soil), 94 *ppm* P (submerged incubated soil), and phosphate sorption coefficient of 1500. It should be noted here that No. 4 soil belongs to the same mapping unit of Singamerta soil used in the pot experiment mentioned later, but that the characters of the soil for the pot experiment were similar to those of the Singamerta soil described by KAWAGUCHI and KYUMA. These soils, which had developed on the alluvial deposits of acid volcanic ashes, contained montmorillonite and kaolinite minerals in their clay fractions and had a high content of quartz in their fine sand fractions. The fact that they had a high iron mobility and that their Bray II-P values increased very much when they were submerged and incubated, are common characteristics of Hydromorphic soils.

Dark Gray Grumusols (No. 5 DM, No. 6 DP, No. 7 NG lowland and No. 8 NG upland):
They were neutral or basic, had a very high CEC and high amount of exchangeable bases, especially exchangeable calcium, and their base saturation degree exceeded 100 %. They had very high clay contents and their soil texture was HC. Upon air-drying they became very hard angular blocks, and on crushing they became angular aggregates. The water dispersibility of their silt-clay fractions was considerably low.

Among those four Grumusols, Nos. 5 and 6 from Central Java seemed to be young and Nos. 7 and 8 from East Java to be old. The former soils were rich in Ca in relation to their CEC and high in inorganic carbon (probably C in $CaCO_3$), and the latter were rich in Mg, very low in inorganic carbon and had a lower amount of free iron than the former. All of them had high total phosphorus content and phosphate sorption coefficient. Although they were rich in Ca, Ca-P was not dominant in their soluble inorganic phosphate fractions. To sum up, these Grumusols were developed under the climate of distinct alternation of dry and rainy seasons on the marine clay deposits derived from eroded, low limestone hills (the former), or on the mixed deposits of clay from the North Limestone Range and neutral and basic volcanic ashes from southern volcanoes, in the basin of the Solo River (the latter).

Regosols (Pyroclastic soils) (No. 9 YG, No. 11 PC):
No. 9 is a basic Grayish Brown Regosol whereas No. 11 is strongly acid and belongs to the Gray Regosol/Lithosol association. Although they have a different reaction, they were developed on the mud-flow deposits of andesitic pyroclastic materials. Strong acidity of No. 11 soil is due to the presence of sulfuric acid originating from sulfur or sulfur compounds contained in pyroclastic parent materials. High water holding capacity and CEC in relation to their clay contents are characteristics of pumiceous volcanic ashes. The presence of very rich amorphous materials in the clay fraction was a common feature of both soils. Very high soluble aluminum in No. 11 soil may have been liberated from the volcanic glass fraction due to strong acidity. Total phosphorus content in No. 9 soil was the highest among the soils studied, and Ca-P was very high in the soluble inorganic phosphorus. Though the phosphate sorption coefficient was low, the available phosphorus contents were not particularly high. No. 11 soil had a slightly high total phosphorus content but the highest iron mobility and available phosphorus content among the soils studied.

Gray Hydromorphic/ Grayish Brown Planosol (No. 10 JK):
This soil was distributed over the nearly flat, northern slope of Rembang Hills which are located west of the North Limestone Range. Parent materials of the soil were sandstone, limestone, marl and claystone of Tertiary formations and this soil was considerably leached out. In addition to its low clay content and high water dispersibility, aggregate formation of the soil was the lowest, and the air and liquid phase ratios and the volume in water were also the lowest, while the bulk density was the highest. Clay leached down from the surface layer formed a hard subsoil with

quartziferous fine sand and silt (DAMES, 1955, p. 110). Wetland rice in pot experiment showed that the soil was markedly deficient in four elements, N, P, K and S (ISMUNADJI, ZULKARNAINI and MIYAKE, 1975). Although the total phosphorus content was the lowest among the soils studied, the phosphate sorption coefficient was the lowest, hence the phosphorus concentration in the equilibrated aqueous solution was the highest.

Reddish Brown Latosol (No. 12 MU):

The soil is derived from tuff of Mt. Salak located south of Bogor, West Java. It had a dark reddish brown color and the highest content of free iron oxide among the soils studied. In spite of its small coarse sand fraction and high clay content, its soil texture was of HC and water dispersibility was low. Consequently, its particle density was the highest, while the bulk density and the solid ratio were low. These physical and chemical properties indicate that the soil is a product of laterization. However, the fact that kaolinite was not clearly recognized in the clay fraction and that amorphous materials were abundant tends to suggest that the soil differs from the Brazilian Latosols which mature completely by laterization. KAWAGUCHI and KYUMA (1977) stated that the so-called Latosols, Mediterranean soils and Regosols derived from pyroclastic materials in Java correspond to the Eutropepts or Dystropepts of the Soil Taxonomy. This suggests that Latosols are similar to the Oxisols in Brazil, whereas in Java, they correspond to the Inceptisols. TAN and PERKINS (1977) also identified a Reddish Brown Latosol from Bogor as Andic Eutropept.

Andosols (No. 13 KR, No. 14 TA- and No. 15 TA+):

They were derived from the volcanic ashes of Mt. Iwate, were black in color and had extremely high humus contents. High percentages of amorphous materials in the clay fractions suggest abundance of allophane in the soils. Soluble aluminum contents in those soils were also high. Total phosphorus contents were high in all the soils studied and especially in No. 15 soil which was collected in the plot fertilized with N, P and K every year. Phosphate fractionation showed that the soils were rich in Al-P. All the soils had high phosphate sorption coefficients and among the three soils, No. 15 had a slightly lower coefficient.

Gray Lowland soil (No. 16 KK):

This paddy field soil preserved for use in pot experiment at the Tropical Agriculture Research Center, was an Alluvial soil of the Kokai River. The presence of particles of colored minerals visible to the naked eye in the coarse and fine sand fractions and the diversified clay mineral composition are considered to be characteristic features of an Alluvial soil in the temperate zone. The soil had a high total phosphorus content, moderate phosphate sorption coefficient and high available phosphorus concentration.

Dark Red soils (No. 17 ME II, No. 18 ME III):

These soils were collected from an upland field in the rainy subtropics and were poor in organic matter. Parent materials of the soils were colluvial and unweathered mineral particles were visible in the soils. Coarse sandy texture of the soil caused leaching down of bases from the surface to the subsurface layer.

ME I referred to the humus-containing horizon at a depth of 0-2 cm in the original profile, but after cultivation this horizon became indistinct and now ME II is the actual surface horizon. These soils had slightly high total phosphorus contents and low phosphate sorption coefficients. Very low available phosphorus concentration of No. 18

soil could be explained from the fact that the reduced condition was not developed in the soil under submergence because of its extremely low iron mobility.

2. Phosphate sorbing capacity and mechanism of phosphate sorption

The definition of the phosphate sorption coefficient indicates that the larger the amount of phosphate sorbed by a soil, the smaller the phosphate concentration in the solution equilibrated with the soil, suggesting that phosphate sorption capacity for soils with high coefficient, such as Andosols, might be relatively underestimated (Fig. 2). In other words, the phosphate sorbed by the soil is equilibrated with a very diluted ammonium phosphate solution. If some more ammonium phosphate were added to the solution, the amount of phosphate sorbed by the soil would be further increased.

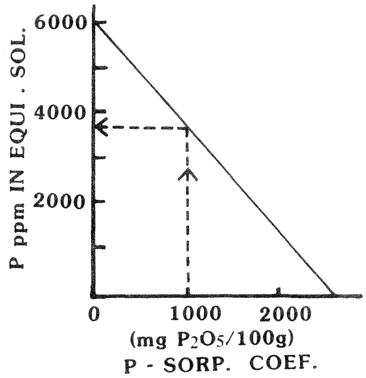

Fig. 2. Theoretical relationship between the concentration of phosphorus remaining in the equilibrated solution and the phosphorus sorption coefficient

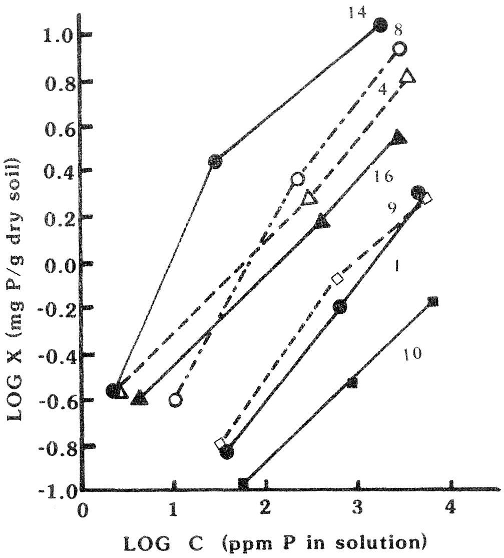

Fig. 3. Relation between phosphate sorbed by soil (X) and phosphate remaining in solution (C) (log X = log k + 1/n log C, k and n are constants

HONYA and YOSHINO (1965) revealed that the phosphate sorption reaction ranging from 10 to 10,000 *ppm* P in the equilibrated solution follows the Freundlich's adsorption isotherm, $X = KC^{1/n}$, in which x is the amount of phosphate (mg P) sorbed by 1 g of soil, C is the concentration of phosphate in the equilibrated solution (*ppm* P), and K and n are constants whose values vary depending on soil and other conditions. Determination of the K and n for each soil enables to calculate the concentration in the equilibrated solution. For andosols, such coefficients at high phosphate concentration may be more effective as compared with the ordinary coefficient. Then, in addition to the ordinary phosphate sorption coefficient determined with a 2.5 % ammonium phosphate solution, the phosphate sorbing capacity was also evaluated by using 0.25 and 0.025 % solutions to draw the regression line, $\log X = \log K + (1/n) \log C$ (Fig. 3). With this equation the phosphate sorption coefficient of C at 4000 *ppm* P was calculated for each soil, as the phosphate concentration in the equilibrated solution for a soil of moderate coefficient (about 1000) is approximately 4000 *ppm* P.

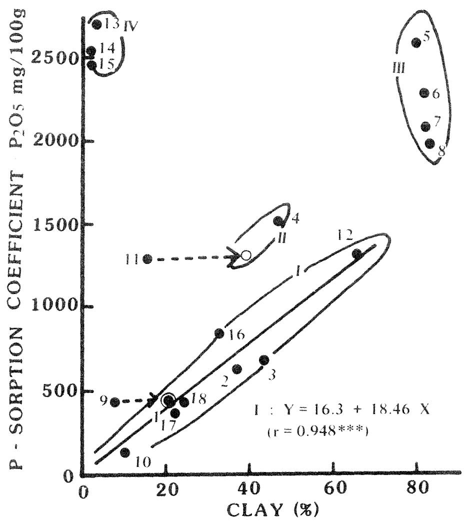

Fig. 4. Relation between the phosphate sorption coefficient and clay content in soil (○ indicates the corrected clay content)

Phosphate sorption coefficients and clay contents:

The relation between the phosphate sorption coefficient and clay content in soil is shown in Fig. 4. The CEC (meq/100g)/clay (%) ratios of Nos. 9 and 11 Regosols of volcanic ash origin amounting to 1.20 and 1.18, respectively were much higher than those of other soils of non-volcanic origin, implying that the porous volcanic ash has an active inner surface in addition to the activity of the outer surface of the particles. The average CEC/clay ratio of non-volcanic soils, 0.48, was applied to both soils to calculate the corrected clay contents which amounted to 20.0 and 38.8 % for Nos. 9 and 11, respectively, as indicated in Fig. 4 by the arrow and dotted line.

From the relationship between phosphate sorption coefficient and clay content, soils studied could be divided into four groups. Positive correlation was observed for the group I soils. If the clay content of No. 9 soil were corrected as mentioned above, the soil could be classified into group I. The same trend could be recognized for the group II soils, although the group consisted of only two soils and the curve tended to move to the higher part of the coefficient. All group III soils were Grumusols with high clay contents and large coefficients, but the relation between both parameters was not proportional. As for the group IV Andosols, clay did not play any significant role in the process of phosphate sorption.

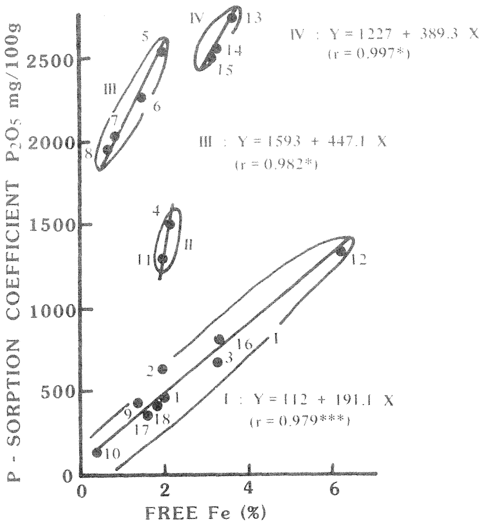

Fig. 5. Relation between the phosphate sorption coefficient and free iron content in soil

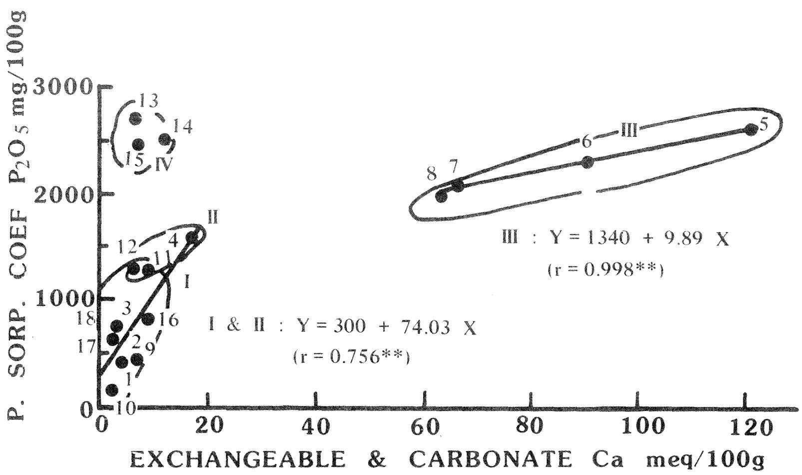

Fig. 6. Relation between the phosphate sorption coefficient and exchangeable calcium + calcium carbonate in soil

Phosphate sorption coefficient and free iron oxide content (Fig. 5):

A positive correlation between the phosphate sorption coefficients and the free iron oxide content could be demonstrated for all the soil groups, although the gradient and position of regression lines varied depending on the groups.

Phosphate sorption coefficient and exchangeable calcium and calcium carbonate (Fig. 6):

Inorganic carbon contents of the Grumusols Nos. 5-8 were 0.61, 0.16, 0.02 and 0.03 %, respectively. The inorganic carbon was assumed to be derived from calcium carbonate and was added to the exchangeable calcium. As shown in Fig. 6, the phosphate sorption coefficient of group III Grumusols increased proportionally to the amounts of exchangeable calcium and calcium carbonate, accounting for their very high coefficients.

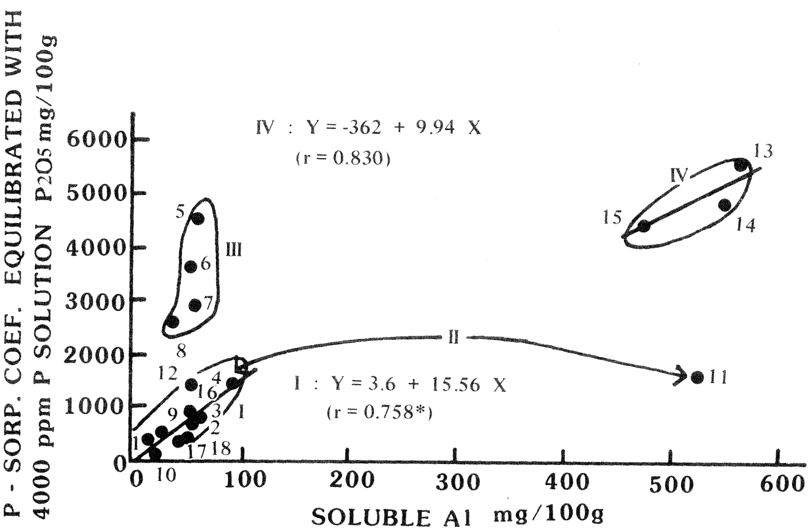

Fig. 7. Relation between the phosphate sorption coefficient (4000 ppm P) and soluble aluminum

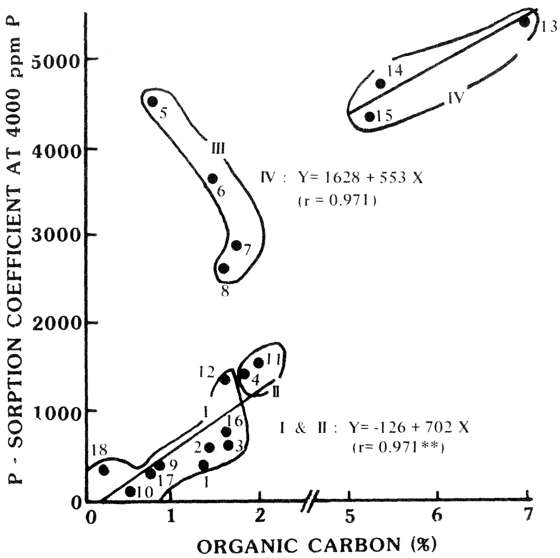

Fig. 8. Relation between the phosphate sorption coefficient (4000 ppm P) and the organic carbon content

Phosphate sorption coefficient, soluble aluminum and organic carbon content:

Since these parameters only relate with group IV Andosols, instead of the ordinary phosphate sorption coefficients, the coefficients (4000 *ppm* P) were used to draw Figures 7 and 8. In these figures, group IV soils were distinguished from group III Grumusols by their higher coefficients. In Fig. 7, the calculated coefficients (4000 *ppm* P) were plotted against the aluminum contents soluble in acetate buffer at pH 4. These Andosols, No. 13, 14 and 15, showed a positive correlation among them, although the correlation coefficient was not high enough to be significant. A similar trend was observed between the phosphate sorption coefficient (4000 *ppm* P) and organic carbon content in Andosols, as shown in Fig. 8. The fact that phosphate sorption coefficients of Andosols are positively correlated with their carbon contents was reported by KATO (1970) in Japanese soils and by BEZAMA and AOMINE (1977) in Chilian soils. YOSHIDA and MIYAUCHI (1975, 1975) stated that the existence of Fe and Al coordinately bound with humus, allophanic Al and free Fe and Al gel is at the origin of the phosphate sorption capacity of Andosols. Extremely high phosphate sorption coefficients of Andosols can be attributed to their very high soluble aluminum contents. This could not be applied to No. 11 Regosol as its coefficient was not as high as its soluble aluminum content, possibly due to the low pH of No. 11 soil caused by the presence of sulfuric acid hindering the sorption of phosphate by soil.

Soils other than the Andosols and acid Regosols gave no evidence to assume that phosphate sorption is related to the presence of soluble aluminum. Study on the phosphate sorption of South Brazilian acid tropical soils by SYER et al. (1971) showed that the sorption of added phosphate was always better correlated with the aluminum parameters such as exchangeable, oxalate and citrate-dithionite-bicarbonate soluble aluminum than with the iron parameters. Another study on the inorganic phosphorus fractionation in Indonesia by LEIWAKABESSY et al. (1973) revealed that the phosphate sorbed by soil was found mostly in the Al-P fraction followed by the Fe-P fraction. As all the soils examined showed that their phosphate sorption was somehow related to their free iron content, it is natural to consider that the phosphate sorption of these soils bore some relation with aluminum components in the soils, although the soluble aluminum content failed to illustrate apparently the relation with phosphate sorption in the case of the soils of groups I, II and III, as shown in Fig. 7.

Phosphate sorption coefficient (1 *ppm* P) and (4000 *ppm* P):

When log C is taken as 0 in the equation $\log X = \log K + (1/n)\log C$, then, $C = 1$ *ppm* P in solution, $X = K$, and K (mg P/g) is the amount of phosphate sorbed by a soil equilibrated with 1 *ppm* P solution. Based on the value of K, the phosphate sorption coefficients (1 *ppm* P) were calculated and plotted against the phosphate sorption coefficients (4000 *ppm* P), as shown in Fig. 9. When an Andosol with a high coefficient was bathed in a 0.025 % solution of ammonium phosphate, the phosphate concentration of the solution decreased to 2-3 *ppm* P.

The ordinary phosphate sorption coefficients of Grumusols (group III) were comparable to those of Andosols, while those at (4000 *ppm* P) were somewhat distinct from those of Andosols and those at (1 *ppm* P) showed marked differences. These facts indicate that the nature of phosphate sorbing components in both soils is different.

The ratio of phosphate sorption coefficient (4000 *ppm* P)/ phosphate sorption coefficient (1 *ppm* P) was calculated in each soil. On an average, it was 61 for all the soils. The average ratio for Grumusols (group III) was 129, for Andosols (group IV) 78, and for the groups I and II 31. The large reduction rate in the amount of phosphate

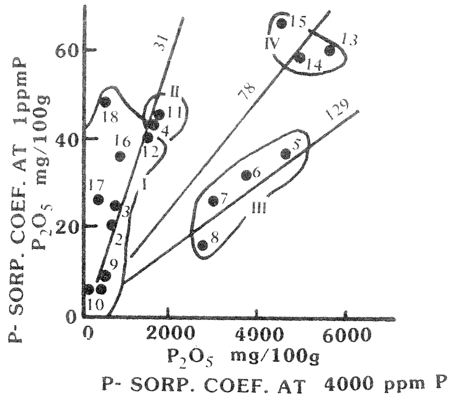

Fig. 9. Relation between the phosphate sorption coefficient (1 ppm P) and (4000 ppm P). The line shows the ratio of P.S.C. 4000/P.S.C. 1 ppm P.

sorbed by a Grumusol which paralleled the reduction in phosphate concentration in the equilibrated solution suggests that the decrease in availability of phosphate added to a Grumusol may be small though the soil shows a very high phosphate sorption coefficient.

To sum up the above discussion, the soils examined could be divided into the following four groups according to their phosphate sorbing mechanism.

Phosphate sorption coefficient of ***group I*** soils, which included Red-Yellow Podzolic soils, a Reddish Brown Latosol, a Gray Lowland soil, a Dark Red soil, correlated with clay and free iron contents, suggesting that the aluminum and iron oxides coated on the clay particles were responsible for the phosphate sorption.

Group II soils consisting of a Gray Hydromorphic soil and a strongly acid Regosol of volcanic origin showed a pattern similar to that of group I, although their coefficients were higher in proportion to clay or free iron contents. This may be due to the fact that the ability of phosphate sorption of aluminum and iron oxides in the group II soils is higher than that in group I, owing to the lower crystallinity of oxides (JUO and ELLIS, 1968). No. 11 Regosol did not show a high phosphate sorption coefficient in spite of its high soluble aluminum content comparable to that of Andosols. This fact suggests that the presence of aluminum soluble in pH 4 acetate buffer solution had no close relation with phosphate sorption.

Soils of ***group III*** were Dark Gray Grumusols. Their high phosphate sorption coefficients were primarily attributed to their high exchangeable and carbonate calcium contents, and partly associated with aluminum and iron oxides coated on the clay.

Extremely high phosphate sorption coefficients of Andosols (***group IV***) showed a correlation with the carbon, soluble aluminum and free iron contents, indicating that aluminum and iron combined with humus are the main sources of the phosphate sorbing capacity of these soils.

3. Phosphorus availability of soils and soil testing methods

Phosphorus uptake by rice seedlings was the highest in No. 4 Hydromorphic soil, followed by No. 11 Regosol. Both soils were rich in iron phosphate and very high in iron mobility. Moderate phosphorus uptake observed in No. 10 Planosol which had high iron mobility may be due to its low total and iron phosphate contents. It could be said, however, that its phosphorus availability was remarkably high considering the lowest total phosphorus content of the soil.

No. 2 Red-Yellow Podzolic soil, No. 7 Grumusol and No. 15 Andosol, all of which were collected from fertilized paddy fields, showed higher uptakes as compared with corresponding non-fertilized soils. No. 6 Grumusol, No. 9 Regosol, which were neutral or basic and had high calcium phosphate contents showed a phosphorus uptake which was not commensurate to their total phosphorus contents. Such findings are in agreement with the observations of CHU and CHANG (1966) who demonstrated that calcium phosphate enters into the composition of coarse particles such as the sand and silt fraction of those soils in the form of apatite, hence the low specific surface activity of the particles.

As soil testing methods for phosphorus availability, various extracting methods were proposed in addition to the method using phosphorus uptake by plants (BINGHAM, 1962).

PAAUW (1971) proposed Pw (mg P_2O_5/liter dry soil) which is the extracting value of a soil with water, the simplest extracting agent, as a parameter closely related with P_2O_5 percentage in plants grown in the soil. He insisted that Pw values can indicate phosphorus availability of soils with a wide range of properties.

AMER et al. (1955) stated that the extraction method with anion exchange resin could recover not only phosphate in the soil solution but also phosphate sorbed by the solid phase, making it possible to estimate simultaneously both intensity and capacity factors of phosphorus availability of the soil. Application of this method was reported from Britain (COOKE and HISLOP, 1968) and Egypt (METWALLY et al., 1975) as a method superior for chemical extraction. OLSEN and WATANABE (1970) also used resin-P as an indicator of sorbed-P. In general, these examples showed that the resin method gave good results for neutral or basic soils.

SHIGA et al. (1973) and SHIGA (1976) recognized that the Bray II method (BRAY and KURTZ, 1945) was applicable to paddy soils in Hokkaido to estimate their phosphorus availability. They illustrated a clear relation between Bray II-P value and the number of tillers at the tillering stage of rice plants or rice yield. KOMOTO (1971, 1977) discussed the relation between Bray II-P values and growth and yield of rice plants in granitic paddy soils in warm West Japan.

Bray II method was considered to be suitable for fertilizer recommendation in Thailand (VAJRAGUPTA et al., 1963) and Peninsular Malaysia (KANAPATHY et al., 1973), both countries having no or a few neutral or alkaline paddy soils. Bray II extracting solution, with a pH of about 1, tends to extract the low available form of calcium phosphate, such as rock phosphate as pointed out by CHANG (1976). Therefore by using the Bray II method it is possible to overestimate phosphorus availability of neutral or alkaline soils rich in calcium phosphate.

Because of its high ability of dissolving iron phosphate, the Olsen method (OLSEN et al., 1954) was recommended by CHANG (1976) for paddy soils in which the main source of available phosphorus for rice plants is iron phosphate.

Comparison and evaluation of various soil testing methods with the results of the experiments mentioned above are presented as follows:

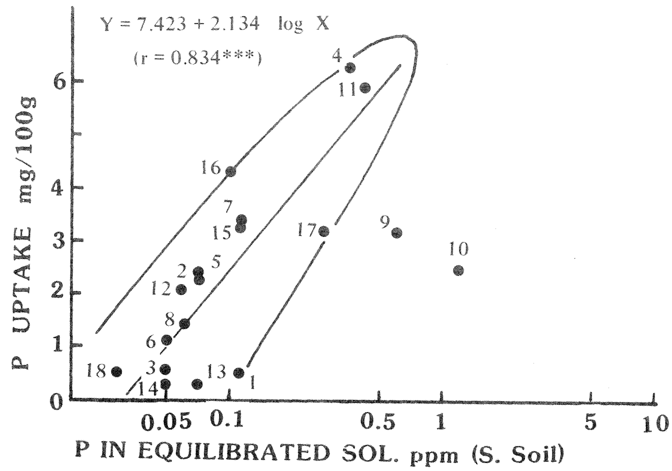

Fig. 10. Relation between the P uptake by rice seedlings and the P content in the supernatant in equilibrium with submerged incubated soil (S. Soil). In the calculation of the correlation coefficient and regression equation, soils outside of the circle were excluded. Three asterisks * of the coefficient indicate 0.1% significance. These symbols can be applied to other figures.**

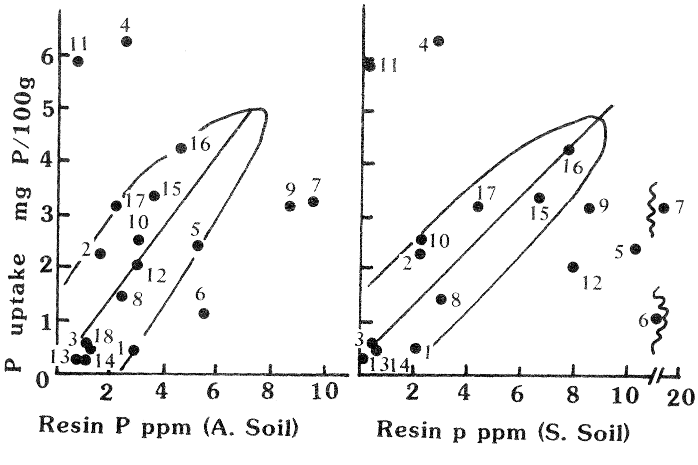

Fig. 11. Correlation between the P uptake by rice seedlings and the resin-P value of air-dried (A. Soil) or submerged incubated soil (S. Soil)

Submerged equilibrated aqueous solution method (Fig. 10)

Logarithm of phosphorus concentration in the supernatant aqueous solution equilibrated with soil (solution-P value) showed a high correlation with the phosphorus uptake by rice seedlings. Detailed examination of the diagram, however, revealed that the solution-P values of Red-Yellow Podzolic soils were in the order of No. 1>No. 2>No. 3, while the phosphorus uptake was in the order of No. 2≫No. 3>No.1. The phosphorus uptake of No. 10 Planosol did not reflect the highest solution-P value among the soils tested. The highest solution-P value with the lowest total phosphorus content of this soil (No. 10) was explained by its lowest clay and free iron contents and, in consequence, phosphate sorption coefficient. These facts suggest that the phosphorus concentration in the equilibrated solution is strongly affected by redox alternation through the transformation of iron in the system. To maintain anaerobic conditions, the test tube with submerged soil was tightly covered with parafilm. However, if even there is a small leakage of air into the tube during the incubation, iron hydroxide is precipitated in the tube containing a soil with high iron mobility such as No. 4, and phosphorus in the solution decreases to an undetectable level. These findings suggest that the equilibrated solution method only indicates the intensity factor of phosphorus availability of a soil. Therefore, when using this method for fertilizer recommendation, it is necessary to combine it with a method indicating a capacity factor, for example, as proposed by FOX et al. (1970)

If Fox's method were to be applied to a paddy soil, anaerobic conditions should be maintained during the whole period from submergence to extraction. KHALID et al. (1979) solved this problem with repeated sealing of N_2 gas into the tube. But, up to now, the method has not been applied successfully to paddy soils having a wide range of properties. Thus, it can be concluded that this method is not practical at present, although it might be improved in the future.

PAAUW (1971) insisted that by restricting the time of shaking of soil and water to 1 hour the migration rate of phosphorus from the solid phase to the liquid phase, which accounts for the capacity factor of phosphorus availability can be revealed. Pw values recorded in Paauw's report were much higher than the solution-P values of Indonesian soils (Pw is expressed in mg/liter, whereas our results are expressed in mg/kg). One of the reasons for such differences may be the difference in soil-water ratio which was 1:5 in our material and 1:60 in Paauw's. It is also possible to consider that the soils tested by Paauw were fertilized repeatedly and that the range of their phosphate sorption capacity did not vary considerably. As the capacity factor of a paddy soil is closely related with its redox potential, the application of the water extraction method to tropical soils makes it difficult to determine the capacity factor in relation to water extracting values as well as low concentrations of phosphorus in the soil solution.

Anion exchange resin method (Fig. 11):

Resin P values of air-dried samples which were less than 10 *ppm* P on a dry soil basis for all the soils were larger than the solution-P values, but lower than those of other extracting methods (Fig. 11 left). It can be seen from the figure that the available phosphorus content of Nos. 4 and 11 soils was underestimated whereas that of Nos. 6, 7 and 9 soils was overestimated. The former soils were rich in iron phosphate and had a high iron mobility, while the latter soils were rich in calcium phosphate or exchangeable calcium and had a pH of more than 7. Considerably low resin-P value of No. 11 soil may be ascribed to delayed phosphate sorption on resin by the sulfuric acid contained in the soil.

Resin-P values of submerged incubated samples were higher in some soils and lower in others and on an average, a little higher than those of air-dried samples. Lower values indicate that phosphate once liberatd under anaerobic conditions may be captured again by iron oxides under aerobic conditions during extraction. Therefore, it could be concluded that the resin method is hardly applicable to paddy soils to evaluate phosphorus availability.

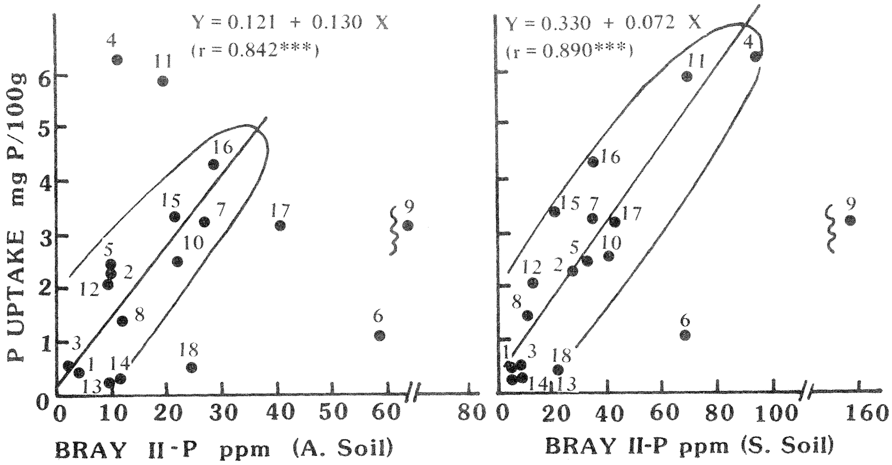

Fig. 12. Correlation between the P uptake by rice seedlings and the Bray II-P value of air-dried or submerged incubated soil

Bray II method:

The relationship between the Bray II-P value of air-dried soil or submerged incubated soil and phosphorus uptake by rice seedlings is shown in Figure 12. Bray II-P values of Nos. 6 and 9 soils were much higher than the phosphorus uptake of rice grown on these soils, which were extremely rich in calcium phosphate (Table 8). Such overestimation of calcium phosphate is, as described in the beginning of this section, due to the fact that the calcium phosphate of these soils exists in the form of comparatively coarse particles of apatite, which is hardly soluble in water.

Overestimation was also observed to a lesser extent in the air-dried samples of soils Nos. 17 and 18, both of which are rich in iron phosphate. This may be due to the fact that the surfaces of coarse sand particles which are abundant in these soils are covered by iron-rust or ferric hydroxide which contains iron phosphate. As a result, the amount of surface phosphorus available to rice plants is relatively small, although the amount of phosphorus chemically extractable is high.

This indicates that the incubation under submerged conditions released a high rate of iron phosphate into the extractable form and led to increased phosphorus availability when measured by the Bray II extraction method. Except for Nos. 6 and 9 soils, Bray II-P values of submerged incubated soils showed a significant correlation with the phosphorus uptake by rice seedlings. Therefore, it can be concluded that the application of Bray II method enabled to evaluate the phosphorus availability of paddy soils, except for those with high pH and high calcium phosphate content.

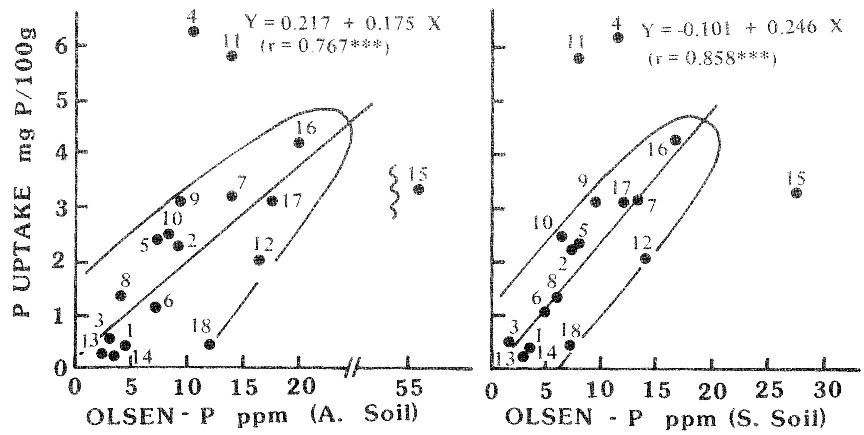

Fig. 13. Correlation between the P uptake by rice seedlings and the Olsen-P value of air-dried or submerged incubated soil

Olsen method (Fig. 13):

Results of Olsen's extraction of air-dried soils or submerged incubated soils are illustrated in Fig. 13 in correlation with phosphorus uptake by rice seedlings. In the case of air-dried soil, P values obtained with Olsen's extraction method were found to be more reliable than those obtained with the Bray II method: there was no overestimation for the soils rich in calcium phosphate or iron phosphate. However, three soils still gave rise to unexpected values, i.e. Nos. 4 and 11 which were on the left side of the regression line and No. 15 which was on the right side far from the line. No. 4 is a Gray Hydromorphic soil and No. 11 is a strongly acid Gray Regosol of volcanic ash origin. As stated previously, both soils with very high iron mobility released large amounts of phosphate under submerged conditions. Extraction of air-dried soil by Olsen solution, thus, failed to estimate phosphorus availability of those soils as shown in the Bray II extraction method. According to JUO and ELLIS (1968), as cited previously, the relative availability of colloidal iron phosphate or aluminum phosphate is very much higher than that of the crystalline form as tested in upland conditions. High iron mobility of Nos. 4 and 11 soils suggested the presence of a higher rate of colloidal form of iron phosphate which may account for the very high phosphorus uptake by rice seedlings grown on those soils.

No. 15 is a soil collected in the annually fertilized plot in the NPK experiment paddy field of Andosol origin. A large amount of aluminum phosphate and iron phosphate is accumulated in the soil. Overestimation of phosphorus content in No. 15 soil may be due to the dissolution of a part of accumulated aluminum phosphate of which only a small amount is available to rice seedlings.

Incubation under submerged conditions generally reduced Olsen-P values as compared to the values of air-dried soils, with a few exceptions. These results suggest that phosphate once extracted from the soil is refixed by ferric hydroxide which is produced again by oxidation of ferrous iron in a medium with high pH during extraction. Therefore, to avoid such phenomenon, EDTA (ASAMI and KUMADA, 1959) was added to the Olsen's extracting solution. The results are presented in Fig. 14. Every Olsen-EDTA-P value of submerged incubated soil was very much higher than the corresponding Olsen-P value of air-dried or submerged incubated soil. All the

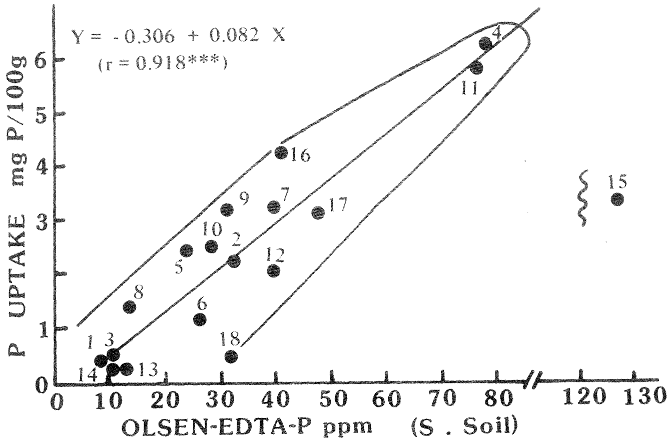

Fig. 14. Correlation between the P uptake by rice seedlings and the Olsen-EDTA-P value of submerged incubated soil. No. 15 soil is a heavily fertilized Andosol sampled at Iwate, Japan

extracting values were within the high correlation range shown in Fig. 14 except for No. 15 soil which is a heavily fertilized Andosol sampled at Iwate, Japan, as mentioned in the preceding paragraph. Since Andosols in Indonesia are mainly distributed along the slopes of volcanoes at higher elevations and are cultivated mostly with various vegetables and flowers originating from the temperate regions (DJOKOSUDARDJO, 1974), rather than with wetland rice, it can safely be said that the Olsen-EDTA method is applicable to almost all kinds of Indonesian paddy soils for determining their phosphorus availability.

Comparison of Olsen-EDTA method with Bray II method:

High correlation was observed between the Bray II-P values and the Olsen-EDTA-P values of submerged incubated soils, as shown in Fig. 15. Except for Nos. 6, 9 soils which gave too high values in Bray II extraction and for No. 15 soil which gave too high values in Olsen-EDTA extraction, a regression equation was obtained from the extracting values as follows:

$Y = 8.261 + 0.825 X$, where X is the Bray II-P value and Y is the Olsen-EDTA-P value. It will be mentioned later in more detail that the lower limit of the Bray II-P value to achieve normal rice growth and yield in a Red-Yellow Podzolic soil must be 15 *ppm* P. This value can be changed to the Olsen-EDTA-P value through the above equation as 20 *ppm* P. As shown in Fig. 15 (broken line), Bray II-P value of No. 12 Latosol was situated within the area of less than 15 *ppm* although the soil never showed phosphorus deficiency even in the plot without phosphorus application, whereas the Olsen-EDTA-P value was situated in the area further over 20 ppm. In contrast, Bray II-P values for Nos. 1, 3, 8, 13, and 14 soils which were considered to be deficient in phosphorus were less than 15 *ppm* and the Olsen-EDTA-P values of these soils were also less than 20 ppm. Therefore, it can be said than the Olsen-EDTA method is superior to the Bray II method for recommendation of fertilizer application to soils with widely varying chracteristics.

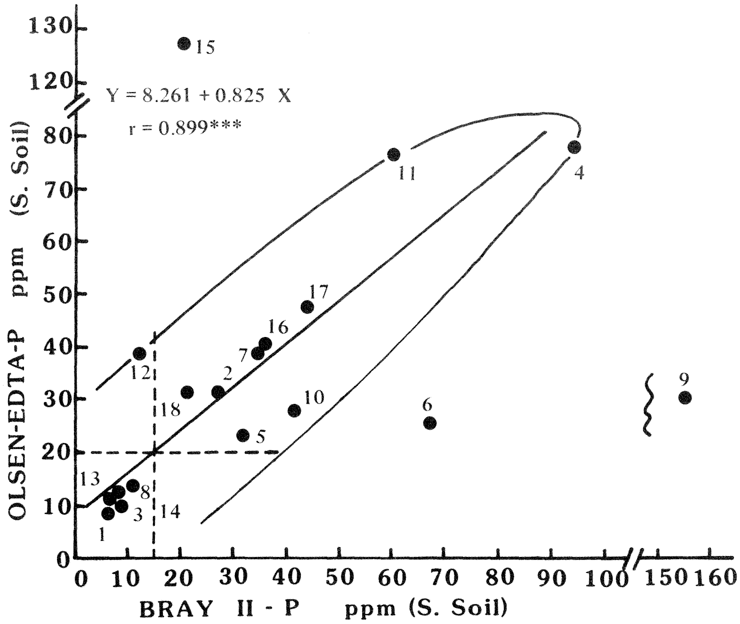

Fig. 15. Relation between the Bray II-P value and the Olsen-EDTA-P value

III Phosphate response of rice in each soil group

Materials and methods

As seen in Chapter II, depending on their properties, soils vary in their ability to supply phosphorus as well as in their capacity and mechanism of sorbing phosphate added. Therefore, the effect of phosphate application on growth and yield of rice plant was studied in pot and field experiments with each soil group.

1. Reddish Brown Latosols

(a) Pot experiment with Muara soil:

A plastic Wagner pot, 1/5000 are in size, was filled with 3.5 kg of air-dried Reddish Brown Latosol (No. 12, Table 1) collected from the Muara Substation of the Central Research Institute for Agriculture, Bogor. Six treatments, namely no-fertilizer application, 0, 0.5, 1, 2 and 3 g P_2O_5 per pot with triple superphosphate (46 % soluble P_2O_5) were carried out with three replications. Except for the pot without fertilizer application all the pots received urea and potassium sulfate at the rate of 1 g of N and 0.5 g of K_2O per pot. Half of the urea was applied as basic dressing and one quarter each as topdressing at the tillering and the flower primordia stages. Three 28-day old seedlings of IR-8 were transplanted in each pot on 24 Sept. 1973.

(b) Field experiment at Muara:

A fertilizer experiment with seven levels of phosphate, 0, 30, 60, 100, 150, 200 and 250 kg P_2O_5 per ha, was carried out at Muara, using triple superphosphate. Each plot was 4 × 6 m in size. The treatments were arranged in a randomized block design with three replications. Nitrogen (urea) was applied 4 times as basic dressing followed by three applications (topdressing) at the tillering stage, flower primordia stage and booting stage at the rate of 40 kg N per ha each. Sixty kilograms K_2O per ha was applied as basic dressing in the form of potassium sulfate. Three 24-day old seedlings of IR-5 were transplanted in each hill with a spacing of 25 × 25 cm on 12 January 1974 (rainy season). After harvest of the rainy season crop, the experiment was repeated during the dry season using plots with the same treatments. Transplanting was on 11 July 1974.

2. Gray Hydromorphic/Grayish Brown Planosols and Yellow Podzolic/Gray Hydromorphic soils

(a) Pot experiment with Jakenan soil:

Each 1/5000 are plastic Wagner pot containing 4 kg of air-dried Planosol (No. 10) collected at the Jakenan Substation was planted with two hills of 14-day old seedlings of IR-5, with three seedlings per hill. There were 6 treatments: no fertilizer (-F), PKS(-N), NKS(-P), NPS(-K), NPK(-S) and NPKS (+F). One gram per pot of each nutrient: N, P_2O_5, K_2O or S was added in the form of NH_4Cl, $Ca(H_2PO_4)_2 \cdot H_2O$, KCl or Na_2SO_4. Seven weeks after transplanting one of three replications was sampled for evaluation of growth performance and chemical analysis. The two remaining replications were harvested 114 days after transplanting.

(b) Pot experiment with Singamerta soil:

Soil taken from a farmer's paddy field located about 1 km west of Singamerta

Substation was used in a pot experiment in applying the same treatment as in 2-(a) (except for 1 g SO_3 per pot instead of 1 g S). Each pot containing 3 kg of air-dried soil was planted with two 24-day old seedlings of IR-5. After 48 days, one replication was sampled. After 130 days, the remaining pots were harvested, the plants in the -S pot where rice growth was retarded were harvested 2 weeks later and those in the -P pot 3 weeks later.

3. Dark Gray Grumusols

(a) Pot experiment with Demak soil:

A pot experiment with soil (No. 5) collected in a paddy field belonging to the Agricultural Extension Service, Demak, was conducted with the same treatments and cultural practices as in experiment 2 (b).

(b) Field experiment in Ngale Substation:

Six levels of phosphate, 0, 30, 60, 90, 120 and 150 kg P_2O_5/ ha of triple superphosphate, were tested in the Ngale Substation (No. 7 soil). Each treatment consisted of 120 kg N/ha as ammonium sulfate in 3 split applications (basic and 2 topdressings) and 60 kg K_2O/ha as potassium sulfate (basic dressing). Three 20-day old seedlings of IR-5 were transplanted in each hill with a spacing of 25 × 25 cm on 20 November 1973. Plants were harvested 120 days later on 20 March 1974.

4. Red-Yellow Podzolic soils

(a) Field experiment in Tamanbogo (I):

Seven phosphate levels, 0, 30, 60, 100, 150, 200 and 250 kg P_2O_5 per ha of triple superphosphate were tested in a paddy field at Tamanbogo Substation. All the treatments consisted of 120 kg urea/ha in three split applications (basic and topdressings at 3 weeks after transplanting and flower primordia stages), and 60 kg K_2O/ha of potassium sulfate as basic dressing. The treatments were repeated 3 times. Plot size was 4 × 6 m. Three 21-day old seedlings of IR-5 were transplanted in a hill, with a spacing of 25 × 25 cm, on 27 February 1972. Plants were harvested on 21 June.

(b) Field experiment in Tamanbogo (II):

Since the rice yields in the experiment (I) did not increase in response to phosphate application another experiment (II) with the same treatments was conducted in a farmer's field 5 km from the substation. Before this experiment, the field (No. 3 soil) was planted with cassava after weeding alang-alang (*Imperata cylindrica*, lalang grass) which had invaded it. Soil pH before treatment was 5.2. Seedlings of IR-5 were transplanted on 10 February 1975. Plants in the 60-250 kg P_2O_5/ha plots were harvested on 10 June and in the 30 kg P_2O_5/ha plot where rice matured later plants were harvested on 18 June. A large part of the plants without P application died before the 10th week after transplanting, and the remaining plants were harvested in July.

(c) Pot experiment with Tegineneng soil (No. 1):

Each 1/5000 are plastic pot, was filled with 4.0 kg of wet Tegineneng soil, which corresponds to 2.52 kg of dry soil. Seven fertilization levels were applied, namely 0, 0.3, 0.6, 1.2, 4.8 and 9.6 g triple superphosphate per pot. These were equivalent to 0, 140, 280, 550, 1100, 2200 and 4420 mg P_2O_5 per pot, respectively. All the treatments were supplied with urea at the rate of 1.0 g N per pot, 1/2 as basic and 1/2 as topdressing 40 days after transplanting, and with potassium sulfate as basic dressing at the rate of 0.6 g K_2O per pot.

Each treatment was duplicated. Four seedlings of the IR-5 variety were transplanted to each pot. Two plants were harvested on the 30th day, one on the 60th day after transplanting and the remaining one plant was harvested on the 129th day.

An incubation test was carried out at the same time as the pot experiment. Eighty grams of air-dried fine soil, which had received the same fertilizer treatment as in the pot experiment, was put into a 250-ml plastic bottle. The bottle was filled up with water and closed tightly with a screw cap. The bottles were placed in a basin with water and the basin was covered with thick black plastic sheets to exclude the sun. All treatments were triplicated. Incubation started on the transplanting day of the pot experiment. One series was sampled on the 30th day, the second series on the 60th day and the last one on the 100th day after transplanting for determination of phosphate in the supernatant solution and Bray II solution extractable phosphorus in soil.

5. Alluvial soils

(a) Field experiment in Winong:

Soils in Winong, Pati, Central Java, are classified as Grayish Dark Brown Alluvial soils. Two kinds of phosphatic fertilizers, triple superphosphate (TSP, citric soluble P_2O_5 46 %) and fused magnesium phosphate (FMP, citric soluble P_2O_5 20 %) were tested on 4 levels, 0, 60, 120 and 180 kg P_2O_5 per ha. To each treatment urea was commonly applied at a rate of 120 kg N and potassium sulfate at a rate of 60 kg K_2O per ha. Seedlings of IR-5 were transplanted on 7 July and harvested on 10 October 1974.

Results

1. Reddish Brown Latosols

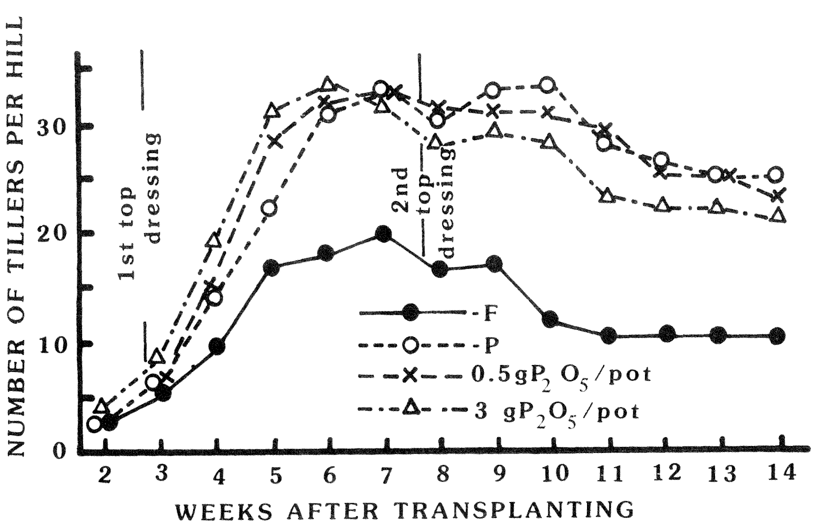

Fig. 16. Tiller number per pot in the phosphate fertilizer experiment (Reddish Brown Latosol, Muara)

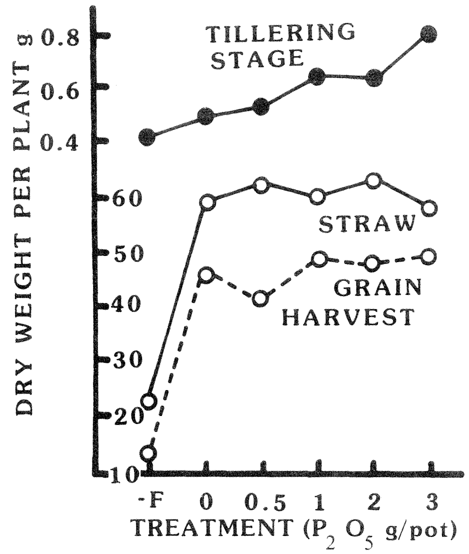

Fig. 17. Dry matter weight in the phosphate pot experiment at tillering stage and harvest (Latosal, Muara)

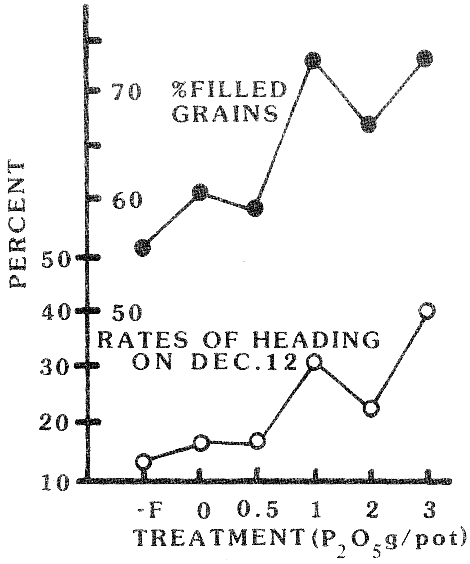

Fig. 18. Percentage of filled grains and rates of heading on 12 Dec. in the phosphate pot experiment (Latosol, Muara)

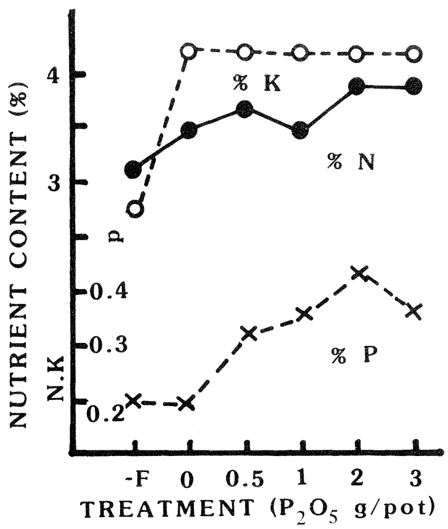

Fig. 19. Nutrient content in plant at tillering stage in the phosphate pot experiment (Latosol, Muara)

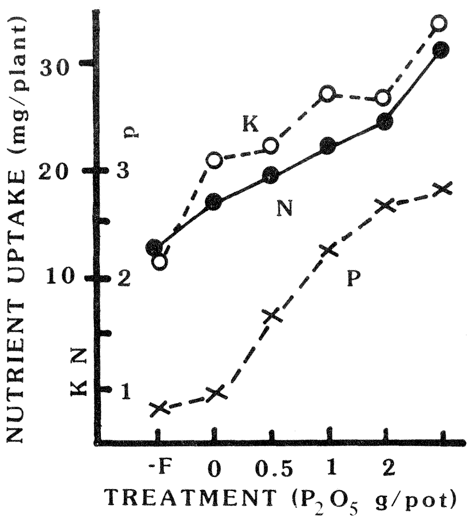

Fig. 20. Nutrient uptake by plant at tillering stage in the phosphate pot experiment (Latosol, Muara)

(a) Pot experiment with Muara soil:

As shown in Fig. 16, plants in the 3 g P_2O_5-pot and those in other pots reached the maximum tiller number stage 6 weeks and 7 weeks after transplanting, respectively. In the pot without P, however, the tiller number increased further after the second topdressing of urea, i.e. at the 10th week.

Six weeks after transplanting, at the tillering stage, the plant height, tiller number, dry matter weight (Fig. 17), phosphorus content in plants (Fig. 19), and the uptake of nitrogen, phosphorus and potassium (Fig. 20) increased with the increasing rate of phosphate application. When phosphate application increased, the heading stage was reached earlier and the percentage of filled grains (Fig. 18) increased. However, significant grain yield differences were not found among the treatments, except for that without fertilizer (Fig. 17).

A significant difference in rice growth was observed between the pot without P and the pot without fertilizer. Without fertilier, rice growth was inferior to that in other pots and the grain yield was only 1/3 to 1/4 of the yield in other pots. In the pot without P, but with nitrogen and potassium, rice growth was inferior to that in the phosphate pots at the maximum tillering stage, but finally growth recovered with an increase in the tiller number.

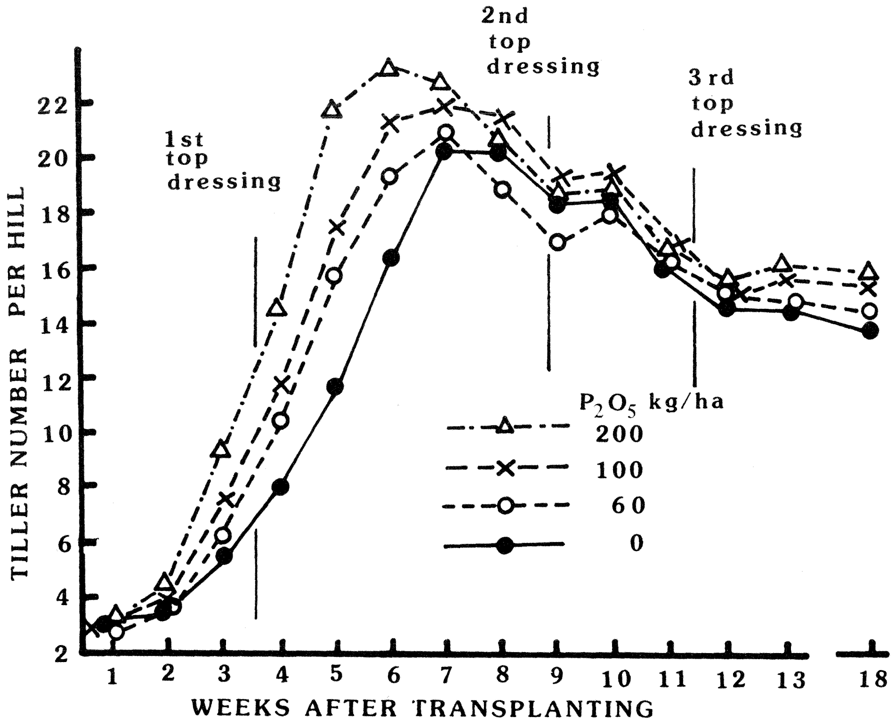

Fig. 21. Change of tiller number as affected by increasing rate of phosphate in the field experiment (rainy season) at Muara (Reddish Brown Latosol)

Table 10. Rice yield and nutrient uptake in the field experiments at the Muara Substation

First field experiment (Rainy season)

Treatment ($kg\ P_2O_5/ha$)	Grain yield kg/ha*	Index	Nutrient uptake (kg/ha) N	P_2O_5	K_2O
0	5553	98	93.8	42.0	129
30	5677	100	87.0	39.8	115
60	5695	100	95.6	50.5	129
100	5760	101	97.0	46.8	124
150	5743	101	98.6	52.4	128
200	5633	99	91.6	46.0	117
250	5567	98	97.1	47.6	137
Mean	5661		94.4	46.4	126

Second field experiment (Dry season)

Treatment ($kg\ P_2O_5/ha$)	Grain yield kg/ha*	Index	N	P_2O_5	K_2O
0	6413	100	89.6	40.7	139
30	6176	96	101.5	45.8	160
60	6098	95	101.4	36.0	174
100	5906	92	88.3	30.0	148
150	5785	90	94.6	39.2	149
200	5872	92	90.9	53.1	166
250	5637	88	86.7	45.1	141
Mean	5984		93.3	41.4	154

* Grain yield adjusted to 14 % moisture

Table 11. Bray II-P values of soils in the first field experiment at Muara Substation

Treatment	Days after transplanting				
($kg\ P_2O_5/ha$)	2	11	24	61	89
0	8	6	8	7	10
30	11	5	11	11	13
60	13	9	11	11	14
100	16	9	11	11	8
150	15	16	11	13	16
200	14	19	9	12	16
250	21	31	9	18	9

(b) Field experiment at Muara Substation:

In the first experiment during the rainy season, the effect of phosphate application on the tiller number was observed until the maximum tillering stage (Fig. 21). Thereafter the difference in tiller number was not as distinct and no significant difference was observed among the grain yields (Table 10). Nitrogen uptake at harvest (87-99 kg/ha) was about 60 % of the amount of nitrogen applied as fertilizer. The uptake amounting to 40-50 kg P_2O_5/ha had no relation with the amount of phosphate applied, while the uptake amounting to 110-140 kg K_2O/ha was about twice as high as the amount of potassium added (60 kg/ha).

Bray II-P values of soils varied in the range of 5 to 30 *ppm* P 90 days after transplanting. They were higher in the plots to which phosphate had been applied especially within 2 weeks after transplanting (Table 11). Correlation coefficients between the Bray II-P values on the 11th day after transplanting and P uptake by plants per a hill on the 24th day or 61st day were 0.712* and 0.805*, respectively.

In the second experiment during the dry season, the effect of phosphate on the increase of the tiller number was clearly recognized, but the highest yield was obtained in the plot without P, and the yield decreased slightly with increasing rate of phosphate application (Table 10).

Field observation on the 56th day after transplanting, i.e. at the flower primordia stage, revealed that the color of rice leaves in the plots with high phosphate levels was more yellowish than that in the lower level plots and this discoloration was due to infestation with bacterial leaf streak. Plant phosphorus contents at flower primordia stage were higher and nitrogen contents were

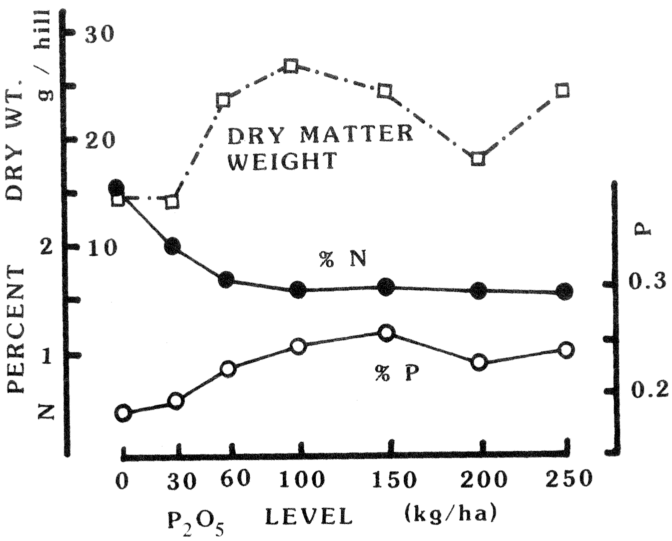

Fig. 22. Dry matter weight, nitrogen and phosphorus content in plant at flower primordia stage (field experiment, dry season, Muara Substation)

lower in the plots with higher levels of phosphate (Fig. 22).

In general, the grain yields in this season were higher than those in the preceding rainy season, and the average nutrient uptakes were 93 kg N, 41 kg P_2O_5 and 154 kg K_2O/ha. Since the N and P uptakes were nearly the same as those of the preceding crop, it can be concluded that the effect of N and P applications on grain production in the dry season crop is higher than that in the rainy season crop.

2. Gray Hydromorphic/Grayish Brown Planosol and Yellow Podzolic/Gray Hydromorphic soil

Table 12. Plant height, number of panicles and dry matter weight of harvested plants (pot experiment, Jakenan soil)

Treatment		Plant height cm	Number of panicles/pot	Dry matter (g/pot) Straw	Panicle
0	-F	72.8	13	15.5	10.6
PKS	-N	75.5	11	16.2	9.8
NKS	-P	87.5	36	58.5	29.6
NPS	-K	78.8	21	27.9	14.1
NPK	-S	70.0	18	22.4	11.1
NPKS	+F	91.0	43	71.2	47.4

Table 13. Iron content in plants on the 47th day after transplanting (pot experiment, Jakenan soil)

Treatment		Fe ppm
0	-F	278
PKS	-N	175
NKS	-P	859
NPS	-K	792
NPK	-S	381
NPKS	+F	1056

(a) Pot experiment with Jakenan soil:

It is clearly seen from the growth and yield of the rice plants at harvest that the soil is severely deficient in nitrogen, potassium and sulfur (Table 12). Although phosphorus content was also considered to be critical in the soil, growth and yield of - P plants were not as inferior as expected, judging from the very low total P content of this soil. At the tillering stage, reddish brown spots were found on the tips and margins of leaves of + F, - K or - P plants. Chemical analyses of such plants revealed abnormally high iron content, as shown in Table 13.

(b) Pot experiment with Singamerta soil:

Changes in the tiller number are illustrated in Fig. 23 and dry matter weight and nutrient uptake are indicated in Table 14. These results show that the soil is deficient in nitrogen, phosphorus and potassium. Lower dry matter weight of +F plants on the 48th day compared with the -K plant may be caused by severe salt injury in the +F pot, as seen from Table 15. At harvest, the straw weight of -P plants was 62 % of the +F plants, and the grain weight of -P plants was only 16 %.

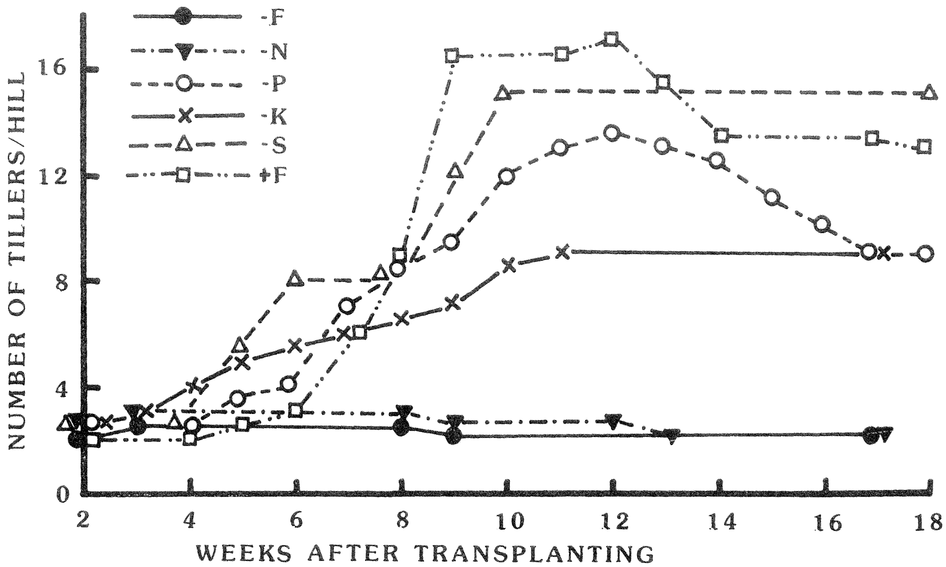

Fig. 23. Change of tiller number in the NPKS pot experiment with Singamerta soil

Table 14. Dry matter weight and nutrient uptake (pot experiment, Singamerta soil)

Treatment		48th day after transplanting				At harvest	
		Dry matter	Nutrient uptake (mg/plant)			Dry matter (g/plant)	
		(g/plant)	N	P	K	Straw	Grain
0	-F	1.55	11.1	3.1	20.5	4.9	4.2
PKS	-N	1.38	8.6	3.3	28.5	5.0	3.4
NKS	-P	2.25	80.5	4.1	50.0	23.1	4.2
NPS	-K	3.58	130.8	13.4	12.2	19.2	3.7
NPK	-S	—*	—	—	—	38.1	12.6
NPKS	+F	3.52	113.3	10.4	90.0	37.4	26.1

* Since one plant died, the determination has not been done in the -S pot.

Table 15. Electric conductivity and pH of surface water (pot experiment, Singamerta soil), 34th day after transplanting)

	EC μmho/cm	pH
-F	740	5.6
-N	2400	5.2
-P	6750	2.9
-K	6100	3.6
-S	7500	3.2
+F	9000	4.5

3. Dark Gray Grumusols

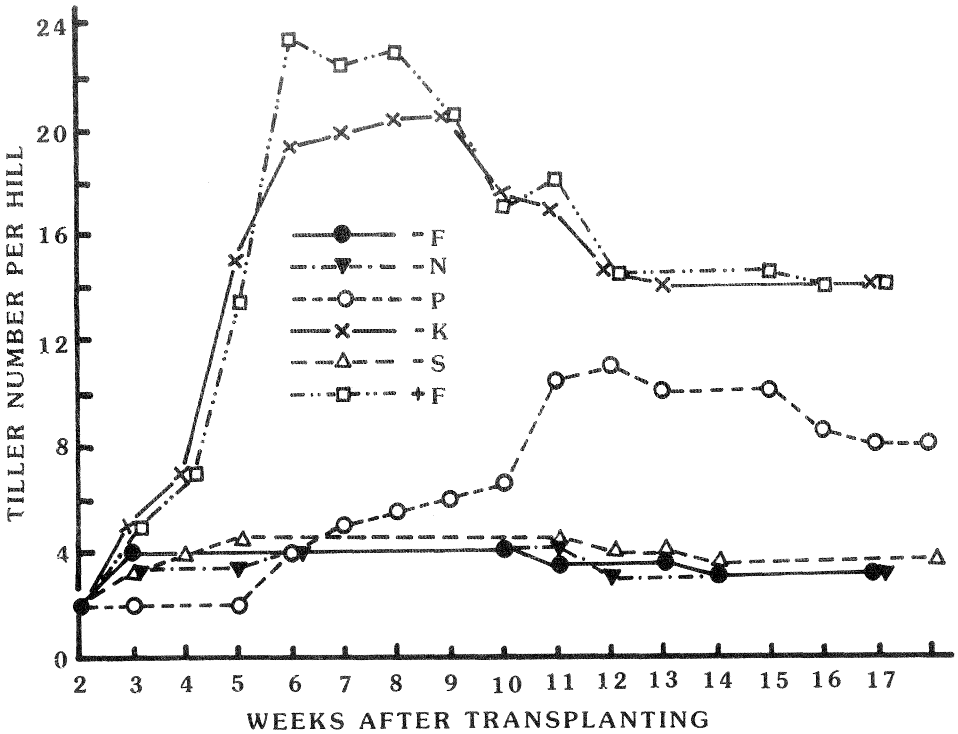

Fig. 24. Change in tiller number during successive growth stages of rice in the pot experiment with Grumusol from Demak

Table 16. Dry matter weight and nutrient uptake (pot experiment, Demak soil)

Treatment		48th day after transplanting				At harvest	
		Dry matter	Nutrient uptake (mg/plant)			Dry matter (g/pot)	
		g/plant	N	P	K	Straw	Grains
0	-F	2.10	15.3	3.1	48.3	6.9	4.3
PKS	-N	2.00	17.8	5.1	48.0	8.7	7.5
NKS	-P	1.32	38.5	1.5	32.9	33.1	18.9
NPS	-K	14.20	338.4	39.3	285.4	68.6	47.4
NPK	-S	2.17	41.0	6.6	31.7	9.4	4.0
NPKS	+F	16.80	346.4	43.0	532.6	66.3	37.6

(a) Pot experiment with Demak soil

Dry matter weight and nutrient uptake on the 48th day after transplanting, presented in Table 16, show that the soil is markedly deficient in nitrogen, phosphorus and sulfur. The dry matter weight of -P plants was only 8 % that of the +F pot. As shown in Fig. 24, the tiller number of -P plants started to increase 6 weeks after transplanting. These facts suggest that phosphorus availability increases at the later stage of rice growth.

Table 17. Tiller number, phosphorus content and uptake of plants in the field experiment at Ngale Substation

Treatment	Tiller number/hill		P content		P uptake	
kg P_2O_5/ ha	Act. till. stage	Flower primordia	% P Act. till.	Fl. prim.	kg/ha Act. till.	Fl. prim.
0	12.2	17.0	0.20	0.22	0.97	7.37
30	12.8	17.2	0.22	0.23	1.05	7.80
60	12.7	17.0	0.25	0.23	1.21	8.34
90	13.2	18.2	0.25	0.23	1.22	9.38
120	13.8	16.3	0.28	0.23	1.15	8.56
150	13.0	16.3	0.27	0.24	1.06	8.68

Table 18. Yield and yield components in the field experiment at Ngale Substation

Treatment kg P_2O_5/ha	Panicles/ m^2	Grains/ panicle	Filled grains (%)	1000-grain wt.(g)	Yield kg/ha
0	253	140	71.0	25.8	5819
30	256	137	72.5	26.2	5997
60	261	133	73.2	26.7	6028
90	243	133	75.7	26.9	6461
120	267	130	69.7	26.7	6430
150	264	139	73.5	25.6	6304

Table 19. Nutrient uptake of harvested plants at Ngale Substation (kg/ha)

Treatment	N	P_2O_5			K_2O
kg P_2O_5/ha	Total	Straw	Grain	Sum	Total
0	80	13	33	46	94
30	77	7	31	38	72
60	78	7	39	45	107
90	76	8	32	40	118
120	81	7	35	43	119
150	83	7	32	39	96

(b) Field experiment in Ngale Substation:

Tiller number, phosphorus content and uptake at maximum tillering stage and flower primordia stage are listed in Table 17 and yield and yield components in Table 18. The effect of phosphorus application was slightly reflected in plant growth at the maximum tillering stage and was not recognized towards the flower primordia stage. Although maximum yield was obtained in the 90 kg P_2O_5/ha plot, yield differences among the plots were not statistically significant. Yield components also did not respond to phosphate application. Nutrient uptake is indicated in Table 19. Mean grain yield was higher and mean phosphorus uptake was lower than the results obtained in the phosphate application field experiment at Muara as described in 1 (b), which was conducted during the same season.

Table 20. Tiller number, nitrogen and phosphorus content of rice plants in the field experiment at Tamanbogo (I)

Treatment	Tiller number per hill*			% N	% P	
P_2O_5 kg/ha	Weeks after transplanting 4	5	6	Active till.	Active till.	Flower primoridia
0	14.3	20.1	22.9	2.76	0.15	0.17
30	21.6	25.6	24.7	2.96	0.20	0.22
60	20.0	22.8	21.8	2.89	0.25	0.22
100	25.0	28.3	26.0	3.26	0.28	0.24
150	24.7	26.1	23.2	3.23	0.25	0.26
200	22.2	23.8	22.7	3.14	0.27	0.25
250	18.5	22.0	20.6	3.32	0.28	0.27

* Maximum tiller number is underlined

Table 21. Yield and yield components in the field experiment at Tamanbogo (I)

Treatment kg P_2O_5/ha	Yield kg/ha	Panicles /m^2	Grains/ panicle	Grains /m^2	Filled grains (%)	1000-grain wt. (%)
				× 1000		
0	3708	243	164	39.8	71.3	24.8
30	3694	237	149	35.3	71.5	25.0
60	3492	224	150	33.5	69.6	24.6
100	3623	227	154	35.0	65.3	24.4
150	3812	237	134	31.9	73.6	25.3
200	3643	219	161	35.2	71.1	25.2
250	3528	229	149	34.0	63.6	24.8

Table 22. Nutrient uptake of harvested plants in the field experiment at Tamanbogo (I) (kg/ha)

Treatment	N	P_2O_5			K_2O
kg P_2O_5/ha	Total	Straw	Grain	Sum	Total
0	90	8	21	29	82
30	82	10	19	29	71
60	81	10	23	33	57
100	85	15	22	37	52
150	79	17	25	42	57
200	75	13	26	39	76
250	80	20	20	40	58

4. Red-Yellow Podzolic soils

(a) Field experiment at Tamanbogo (I):

Changes in tiller number, nitrogen and phosphorus content are presented in Table 20, yield and yield components in Table 23, and nutrient uptake in Table 22. The effect of phosphate application was manifested by an increase in the tiller number and slightly higher nitrogen or phosphorus contents of plants at the tillering stage. However it could not be recognized as far as the yield was concerned. Compared with the results obtained in the other two substations, namely Muara [1-(b)] and Ngale [3-(b)], during the same season and with the same treatments, the grain yields in Tamanbogo were generally low, suggesting the existence of some adverse soil conditions which could not be corrected by the application of three fertilizer elements, N, P or K alone. There was no difference in the N uptake in the three substations, while K_2O uptake was in the order of Muara >Ngale>Tamanbogo, indicating that one of the adverse factors may be the deficiency in bases, especially calcium and magnesium.

Table 23. Yield and yield components in the field experiment at Tamanbogo (II)

Treatment P_2O_5 kg/ha	Yield (14 % H_2O) kg/ha	Panicles $/m^2$ no.	Grains/ panicle no.	Grains $/m^2$ × 1000	Filled grains %	1000-grain wt. g
0	19	25	6	0.2	65.7	23.2
30	964	176	24	4.2	74.4	26.3
60	2622	206	56	11.5	75.1	26.8
100	3616	211	77	16.2	74.5	26.9
150	3871	211	79	16.7	75.6	27.0
200	3715	235	71	16.7	74.9	26.6
250	3660	213	74	15.8	75.3	26.8

Table 24. Phosphorus uptake by rice plants in the field experiment at Tamanbogo (II)

Treatment	Percentage phosphorus				Uptake at harvest kg P_2O_5/ha			Utilization
P_2O_5	Active	Flower	Harvest					ratio of
kg/ha	till.	prim.	Straw	Grain	Straw	Grain	Sum	fert. P (%)
0	0.04	0.07	0.08	0.06	0.19	0.04	0.2	—
30	0.09	0.09	0.05	0.10	2.68	3.03	5.7	18.2
60	0.10	0.11	0.05	0.12	4.37	7.45	11.8	19.3
100	0.13	0.12	0.07	0.16	9.61	17.35	26.9	26.7
150	0.14	0.15	0.07	0.21	10.00	24.05	34.0	22.8
200	0.14	0.15	0.10	0.21	13.87	24.09	37.9	18.9
250	0.16	0.18	0.13	0.22	17.81	23.95	41.7	16.6

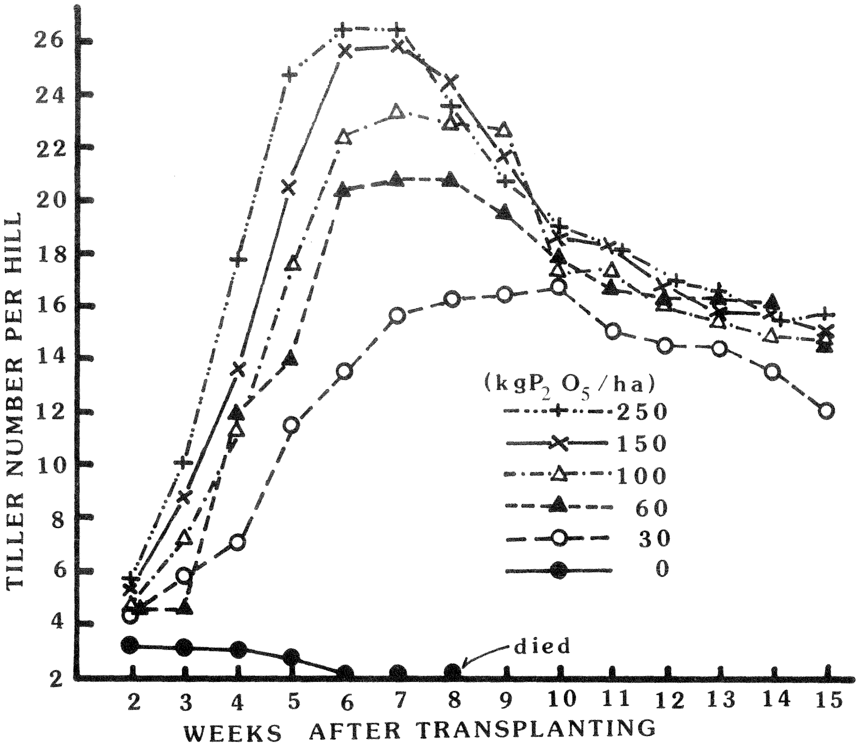

Fig. 25. Tiller number as affected by increasing rate of phosphate application at farmer's paddy field (Red-Yellow Podzolic soil, Tamanbogo)

(b) Field experiment at Tamanbogo (II):

Yield and yield components are presented in Table 23, phosphorus contents of plants at successive growth stages, and phosphorus uptake and utilization ratio of phosphate fertilizer are shown in Table 24. Changes in tiller number are indicated in Fig. 25. As mentioned previously, most of the plants without P application died before the 10th week after transplanting, and in the 30 kg P_2O_5/ha plot, considerable delay in tillering resulted in very low panicle number. In the first field experiment at Muara Substation, [1(b)], the effect of phosphate application in increasing tiller number was clearly observed, but the maximum number of tillers and the time to reach the stage were not affected by the amount of phosphate applied. In Tamanbogo, no delay in reaching the maximum tiller number stage was observed in the plots with more than 100 kg P_2O_5/ha.

The effect of increasing rate of phosphate application on rice yield was remarkable, although the highest yield in Tamanbogo was far less than the average yield in Muara or Ngale. The highest grain yield was obtained at a dose of 150 kg P_2O_5 per ha, while the highest yield increment and utilization ratio of fertilizer phosphorus were achieved at a rate of 60 kg and 100 kg P_2O_5 per ha, respectively.

Table 25. Yield and yield components (pot experiment, Tegineneng soil)

Treatment g TSP/pot	Panicles no./pot	Grains no./panicle	Filled grains no./pot	1000-grain wt. (g)	Dry wt./pot Straw (g)	Dry wt./pot Grain (g)
0	0	—	—	—	—	—
0.3	4.5	131	526	25.5	14.2	14.5
0.6	6.0	159	816	27.0	19.3	24.2
1.2	7.0	154	844	27.0	21.6	25.4
2.4	8.0	141	844	25.8	20.6	25.4
4.8	7.0	145	832	26.0	19.7	25.5
9.6	7.5	149	965	25.1	19.4	26.3

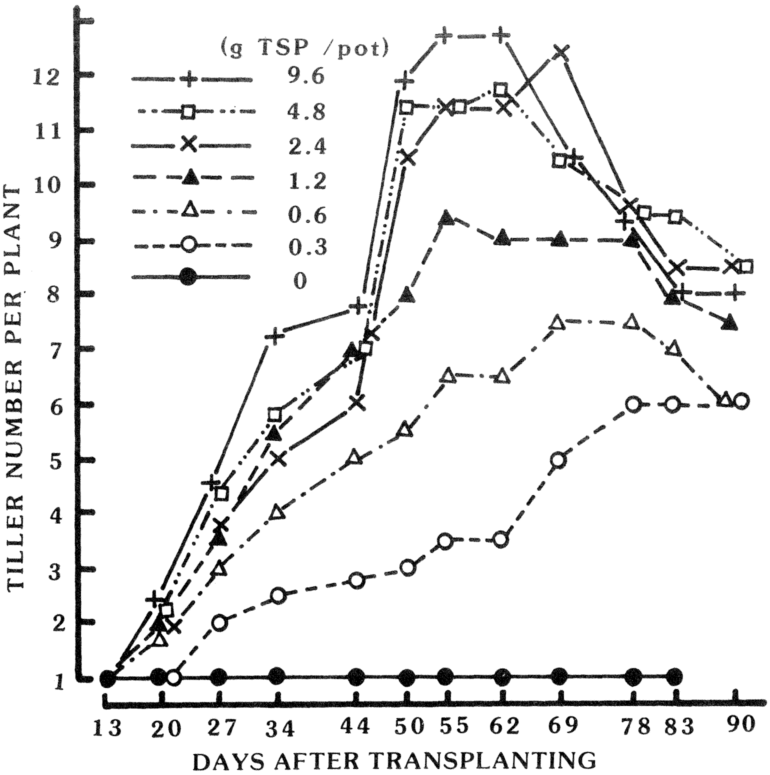

Fig. 26. Change in tiller number as affected by increasing rate of phosphate application in the pot experiment with Red-Yellow Podzolic soil from Tegineneng

(c) Pot experiment with Tegineneng soil:

Changes in tiller numbers are shown in Fig. 26. Absence of growth, manifested by the decrease in tiller number and absence of increase in plant height, was observed in the pots without P application. The plants died approximately 80 days after transplanting. Phosphate application before the maximum tillering stage was very effective in increasing tiller number. Significant differences were also observed in the maximum tiller numbers of plants subjected to the treatments of 0 - 2.4 g TSP/pot, while in the treatments with more than 2.4 g TSP/pot, there was little difference in both the tiller number increase and the maximum tiller number.

Yield and yield components are listed in Table 25. Panicle number increased with the increase in TSP supply up to 2.4 g per pot while grain yield increased up to 1.2 g.

Table 26. Soil pH and Bray II-P values of Tegineneng soils incubated under submerged conditions

Treatment		30th day			60th day			100th day		
TSP g/pot	P mg/100g	pH	Bray II-P mg/100g	Recov. ratio (%)	pH	Bray II-P mg/100g	Recov. ratio (%)	pH	Bray II-P mg/100g	Recov. ratio (%)
0	0	6.9	1.2	—	7.0	1.0	—	6.6	0.5	—
0.3	2.4	7.0	1.1	0	7.1	1.0	0	6.0	0.6	4.2
0.6	4.8	6.9	1.0	0	7.0	1.1	2.1	6.4	0.9	8.3
1.2	9.6	6.9	1.1	0	7.1	1.6	6.3	6.2	1.4	9.4
2.4	19.1	6.9	2.5	6.8	7.1	3.3	12.0	6.1	1.8	6.8
4.8	38.2	6.9	6.8	14.7	7.1	7.8	17.8	6.0	5.1	12.0
9.6	76.5	6.9	25.4	31.6	7.0	24.9	31.2	6.0	21.7	27.7

Recovery ratio = (Bray II-P of fertilized soil — Bray II-P of non-fertilizer soil)/Amount of fertilizer P added × 100 (%)

Analytical results of incubated soil samples are presented in Table 26. Before soil sampling, phosphorus concentration in the supernatant water in the bottle was determined. On the first sampling, 30 days after transplanting, 0.7 *ppm* P equivalent to about 0.2 mg P per bottle was detected in the water of the bottle containing the highest dose of TSP, namely 61 mg P (9.6 g TSP/bottle). In the other bottles, including all those of the second and third sampling, water-soluble P could not be detected. This indicates that almost all of the added phosphate was sorbed by the soil and was in an insoluble form.

Since soil in the bottle containing soil without P application showed Bray II-P values of 1-1.2 mg P/100 g, the values of more than 1 mg P/100 g which were recorded were assumed to be derived from added phosphate. Fertilizer phosphorus could be recovered from the 30th day sample soils which received more than 2.4 g TSP per pot, and from the 60 and 100th day sample soils which received more than 1.2 g TSP per pot, equivalent to about 10 mg per 100 g of soil. In an actual paddy field, this concentration is equivalent to 250 kg P_2O_5 per ha of phosphate applied.

From the results of analyses of soil, plant growth and yield, it could be concluded that tiller number increase occurs up to 2.5 mg P/100 g and yield up to only 1.5 mg P/100 g of Bray II-P in soil at the maximum tillering stage. Both values were used to make Table 31.

Table 27. **Yield and nutrient uptake of rice plants in the field experiment at Winong**

Treatment	Tiller. stage		Nutrient uptake at harvest		
P_2O_5 kg/ha	P uptake mg/plant	Yield kg/ha	N	kg/ha P_2O_5	K_2O
0	16	4627	80	30.6	134
60 (TSP)	20	4712	83	31.2	147
120 (TSP)	21	5404	88	37.9	154
180 (TSP)	21	4847	80	30.1	140
60 (FMP)	19	4953	78	25.9	140
120 (FMP)	20	5042	82	36.5	135
180 (FMP)	23	4839	83	40.0	142

5. Alluvial soils

(a) Field experiment at Winong:

Grain yield and nutrient uptake are shown in Table 27. The effect of TSP on rice growth at the early stage could be observed in the phosphorus uptake at the active tillering stage, while in the case of other growth parameters, such as plant height, tiller number, and contents of N and K in the shoots, hardly any response was observed. Furthermore, neither the yield nor the yield components responded to phosphate application, although application of 120 kg P_2O_5 of TSP gave rise to the highest yield.

Discussion

When the results of the rice experiments are evaluated and the soil characteristics are taken into account, the relation betwen rice growth and soil can be analysed to provide guidelines on fertilizer application.

1. Reddish Brown Latosols

Reddish Brown Latosol (No. 12) in the Muara Substation of the Central Research Institute for Agriculture, Bogor, West Java, is derived from neutral tuff originating from the eruption of Mt. Salak. As stated in the previous chapter, KAWAGUCHI and KYUMA (1977) and TAN and PERKINS (1977) demonstrated that these kinds of Latosols and related soils are not Oxisols but Eutropepts. However, such classification did not imply that the soil has no latosolic character, because it is a heavy clay containing 67 % of Calgon-dispersible clay fraction and only 1.2 % of water-dispersible clay fraction (Tables 2 and 3), and has a low bulk density (93) compared with the very high particle density, (2.93). These findings suggest the formation of iron oxide-cementing aggregates in the soil. The cation exchange capacity of 17 meq/100 g, is not as high as the clay content, but it is higher than that of Brazilian Latosols. The same consideration applies to the base saturation degree of 56 %.

Although the effect of phosphate application on rice growth was observed to some extent at the tillering stage, grain yield failed to show any response to phosphate application and sometimes a negative effect on the yields was even recorded.

In spite of its high total phosphorus content, 250 mg P_2O_5 per 100 g on an average (Table 28), as in Indonesian soils, phosphorus concentration in the solution equilibrated with the soil was extremely low. The Bray II-P values were also low and hardly increased by submergence, suggesting that the soil has a small intensity factor and large capacity factor for supplying phosphorus. When the growth of rice roots becomes satisfactory after nitrogen application which promotes phosphorus uptake by the plants, a low availability of soil phosphorus (intensity factor) would not become a critical factor for grain yield.

Phosphorus is strongly concentrated into the actively growing tissues of plant organs. When the phosphorus supply is depressed, the activity of the growing points is reduced. In case of the rice plant, the increase in tiller number per hill or in spikelets on a young panicle is delayed (MIYAKE et al. 1971). In areas at higher latitudes, such as the northern part of the temperate zone where the rice growing season is limited by a low temperature, a delay in rice growth is associated with a decrease in yield; in the tropics where high temperatures occur all the year round, faster growth promoted by phosphate application has little significance on rice yield. Furthermore, retarded growth caused by low phosphorus availability prolongs the period of vegetative growth and tends to increase rice yield. This can be experienced even in countries at high latitudes during years when the summer temperature is high. The same applies to the yield increase in the low phosphate plots of experiment 1 (b). In this case, higher phosphate application resulted in increasing the susceptibility of the plant to bacterial leaf streak. Bacterial invasion of green leaves decreased their photosynthetic ability, hence the decrease in yield.

From the standpoint of phosphorus nutrition, rice growth and yield in Muara were compared with those obtained in three prefectural agricultural experiment stations in Japan (YANAGIZAWA and TAKAHASHI, 1964). According to this report, the soils in those stations were found to contain enough phosphorus to sustain normal growth and yield of wetland rice. Monthly mean temperatures during the rice growing season are shown in Fig. 27. In Japan, the transplanted seedlings reach the tillering stage under low temperature in early summer and the heading stage in the warmer late summer. Temperatures become lower again during the maturing period. On the other hand, in Bogor the range of monthly fluctuations in temperature is very small.

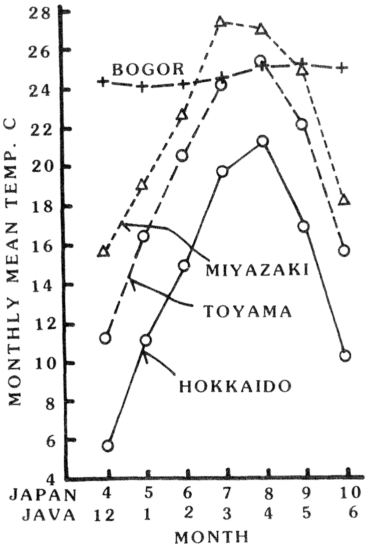

Fig. 27. Monthly mean temperature of selected stations for rice growing season

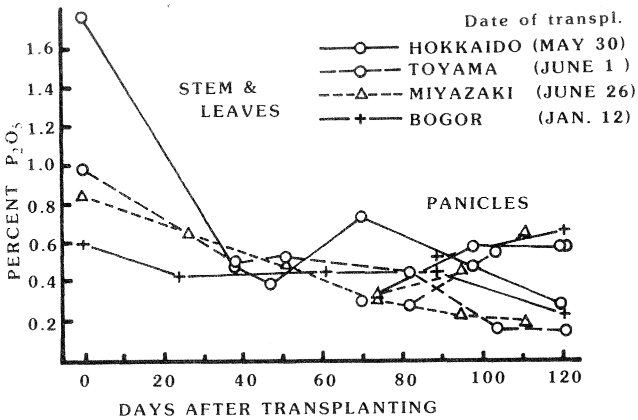

Fig. 28. Change in phosphorus content in plant at selected stations

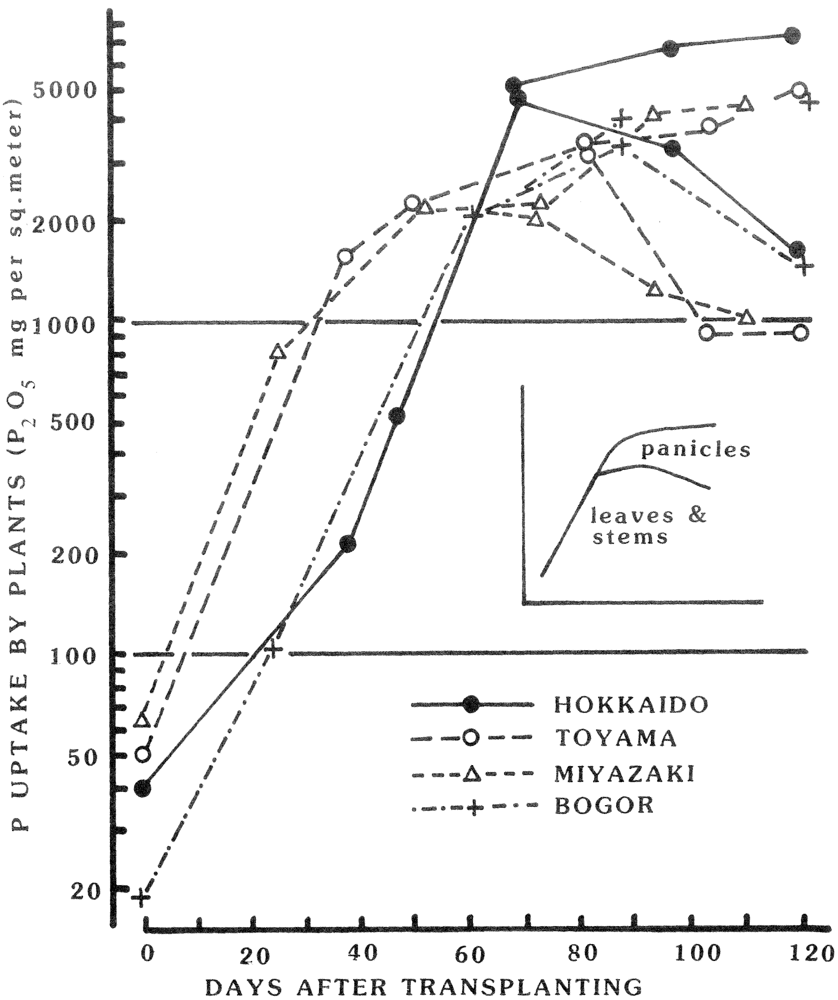

Fig. 29. Phosphorus uptake of rice plant at selected stations in Japan and Indonesia

When Fig. 27 was correlated with Fig. 28, in which the phosphorus contents in plants at the selected stations were plotted against the days after transplanting, it was found that a lower temperature at transplanting time was correlated with a higher percentage of P_2O_5 in the rice seedlings. This suggests that rice seedlings rich in phosphorus can overcome retarded phosphorus uptake caused by low temperature and are able to increase the tiller number rapidly. In Fig. 29, the phosphorus uptake by the rice plants grown at the selected stations is illustrated on a semilogarithmic scale. In Figures 28 and 29, the data points for Bogor are the average values of percent P_2O_5 or P_2O_5 mg per m^2 of all the treatments in the first experiment during the rainy season at Muara, 1 (b). The rice seedlings in Muara had the lowest phosphorus content and uptake, but the highest rate of uptake was maintained during 60 days after transplanting, indicating that the rice plants grown in Muara could absorb a sufficient amount of phosphorus from the soil for normal growth under the Bogor temperature regime, although this soil had a rather low phosphorus availability. In the later growing stages, little differences in phosphorus content and uptake were observed among the stations.

Table 28. Total phosphorus contents of paddy soils at the Muara Substation (Reddish Brown Latosol)

Soil			P_2O_5 mg/100 g	Soil		P_2O_5 mg/100 g
Soils from the field experiment				No. 12 soil (Table 1)		337
III-1-(b)	Treatment			Soil for the pot exp. III-1-(a)		229
	0	kg P_2O_5/ha	261	Soils from the paddy field with long-		
	30	〃	286	term fertilizer experiment after 7 crops		
	60	〃	328	Treatment	0-0-0	170
	100	〃	296		0-60-0	201
	150	〃	275		120-0-0	167
	200	〃	309			
	250	〃	289	Mean 262 mg P_2O_5/100 g = 1140 ppm P		

Table 29. Yield, phosphorus content and uptake of rice plants cultivated in four experiment stations in Japan* and Indonesia

Experiment station	% P_2O_5 Straw	Grain	Uptake P_2O_5 kg/ha	Yield (brown rice) kg/ha	Yield/ P_2O_5
Hokkaido	0.28	0.58	63.8	7210	113
Toyama	0.15	0.58	35.1	4050	115
Miyazaki	0.19	0.64	39.2	4370	111
Bogor (Muara)	0.23	0.66	46.4	4129	89

* YANAGISAWA and TAKAHASHI (1964)

Brown rice yields, phosphorus contents and uptakes of harvested plants in the selected four stations are indicated in Table 29. Total phosphorus uptake in Bogor was slightly higher and the brown rice yield was slightly lower than the average yield recorded in 16 Japanese experiment stations including the above three stations, which amounted to 43.2 kg P_2O_5/ha and 4,890 kg/ha, respectively (YANAGIZAWA and TAKAHASHI, 1964). Consequently, yield per unit phosphorus uptake was relatively low in Bogor rice and in a way, rice in Bogor does not appear to require high soil phosphorus availability in the early stages of growth. However, this fact does not necessarily imply that the phosphorus requirement of tropical rice is low, because the phosphorus uptake by Bogor rice was higher than that by Japanese or other temperate rices.

As shown in Table 28, total phosphorus contents of paddy soils in Muara Substation ranged from 170 to 340 mg P_2O_5/100 g with an average of 260 mg P_2O_5/100 g. FUJIWARA (1970) statistically analysed total and active phosphorus contents of paddy soils in several Southeast Asian countries and reported that the presence of a total phosphorus content as low as 50 mg P_2O_5/100 g suggested that there was no active phosphorus in soil. If a value of 200 mg of P_2O_5 is assumed to represent the amount of available phosphorus in soil this would correspond to 3,000 kg P_2O_5 per ha of soil at a depth of 15 cm, or the equivalent of 60 crops, assuming rice removes 50 kg P_2O_5/ha every cropping season. However, phosphorus deficiency can be observed in Red-Yellow Podzolic soil (No. 3) with 80 mg P_2O_5/100 g of total phosphorus, suggesting that the critical value of total phosphorus content in tropical reddish colored soils where there is no available phosphorus is likely to be higher than the 50 mg P_2O_5/100 g mentioned above.

Results of the pot experiment 1 (a) showed that with an appropriate amount of nitrogen and potassium the Muara soil enabled to achieve normal rice yields without phosphorus application. In the field experiment 1 (b) in the rainy season, the highest yield was obtained in the plot without P application and the increased rate of phosphate resulted in a yield decrease. This indicates that phosphate application is not necessary in this soil.

Phosphate application at a rate of about 20 - 30 kg P_2O_5/ha would be recommended for paddy fields with such Reddish Brown Latosols for the following reasons: 1) yield decrease by increased phosphate application is partly due to bacterial leaf streak, and a variety resistant to this disease is available now (MUELLER, 1970), 2) removal of straw and grains from the field is equivalent to a quantity of 50 kg P_2O_5/ha for a cropping season and removal of grain to only 30 kg P_2O_5/ha, 3) phosphatic fertility of a soil is related to the maintenance and enhancement of nitrogen fertility through the activities of various soil microorganisms, 4) amounts of phosphate recommended should not be a heavy burden for the farmer's household.

2. Gray Hydromorphic/Grayish Brown Planosols and Yellow Podzolic/Gray Hydromorphic soils

Characteristics of the soils tested are summarized as follows:-

Jakenan soil: The soil map of Central Java (1: 250,000) published by the Soil Research Institute, Bogor, showed that Jakenan Substation is located in an area where a Gray Hydromorphic and Grayish Brown Planosol association is known to exist. As described in Chapter II, this soil is a highly leached fine sandy loam consisting mainly of quartziferous fine sand and silt fractions, and has a cation exchange capacity of 4 meq/100 g, a base saturation degree of 63 %, and a free iron content of 0.4 %. Its very high phosphorus concentration (1.2 *ppm* P) in the equilibrated solution, may be ascribed to its very low phosphate sorption coefficient, (150) in spite of its very low total phosphorus content (40 mg P_2O_5/100g). Consequently, the phosphorus uptake by rice seedlings from this soil was higher than that of the Reddish Brown Latosol from Muara. The soil, containing small amounts of free iron, is easily reduced under the anaerobic conditions, and therefore has high iron mobility.

Singamerta soil: No. 4 soil (Table 1) was collected in a farmer's paddy field 500 m west of Singamerta Substation. The soil for the pot experiment, which was collected in another farmer's paddy field 1 km south of the station belonged to a mapping unit of Yellow Podzolic and Gray Hydromorphic soil association, in the soil map of West Java. Its fertility was likely to be lower than that of No. 4 soil, although both of them have similar hydromorphic properties. Total phosphorus content of No. 4 soil was 114 mg, that of the soil of the Substation 74 mg (according to KAWAGUCHI and KYUMA), while that of the soil for experiment 2 (b) was as low as 40 mg P_2O_5/100 g. Therefore, the phosphatic fertility of this soil can be assumed to be nearly the same as that of the Jakenan soil. The soils from Jakenan and Singamerta stations had a high iron mobility.

As shown in Table 15, Singamerta soil has a very small buffering capacity when salt concentration rises. For example, the electrical conductivity of the surface water in the pot without fertilizer was 740 μmho/cm and the pH 5.6, and in the pot with complete fertilizer application 9000 μmho/cm and the pH was 4.5.

DUDAL (1973) discussed the genesis of Planosols and stated that with continued ferrolysis a seasonally wet soil can eventually become a gray, unstable, silty or sandy soil with low clay content and very low cation exchange capacity. Ferrolysis (BRINKMAN, 1970) is a soil forming process whereby during the anaerobic phase exchangeable cations are displaced by ferrous iron, while in the succeeding aerobic phase ferric hydroxide and hydrogen ions are produced and hydrogen ions corrode the octahedral layers of clay minerals at their edge. Some remarkable properties of Jakenan soil can be ascribed to such forming process. Singamerta soil is also undergoing a smilar soil forming process, though different to some extent.

As a result of ferrolysis, the Planosol from Jakenan contains very little free iron which can fix phosphorus and it undergoes oxidation and reduction readily. Thus, the soil has high water soluble or available phosphorus contents in spite of its very low total phosphorus content. On the other hand, its high iron mobility suggests the possibility that iron or manganese toxicity of wetland rice may occur. In the experiment 2 (a), the leaves of the rice plants supplied with nitrogen and sulfur, which are markedly deficient in the soil, showed tiny brown spots and a brown discoloration of their tips and margins after the maximum tillering stage. As shown in the chemical analysis in Table 13, the leaves had a high content of iron.

Reddish Brown Latosol from Muara described in the preceding section, which contained 260 mg P_2O_5/100 g of total phosphorus and 0.006 *ppm* P in the equilibrated solution, showed an adequate phosphorus supplying ability for normal rice growth if only nitrogen fertilizer was applied. In contrast, the Planosol from Jakenan had a high phosphorus concentration in the equilibrated solution, i.e. more than 1 *ppm* P, and yet rice growth on the soil responded to phosphate application suggesting that the capacity factor of phosphorus availability was insufficient to replenish the phosphorus concentration depleted by rice uptake.

If the soluble phosphate content of Jakenan soil, i.e. the sum of Ca-P, Al-P and Fe-P, is assumed to reflect the potentially available phosphorus, the value amounts to 20 mg P_2O_5/100 g, which is equivalent to half of the total phosphorus content. This value corresponds to an application of about 200 kg P_2O_5 per ha of cultivated soil, and could supply enough phosphate for five rice cropping seasons, (40 kg P_2O_5/ha/crop), which is very low compared with 60 seasons for the Muara soil. Since Planosols and Hydromorphic soils with low total phosphorus content are usually highly deficient in nitrogen, potassium and sulfur, phosphate application can only be effective after the application of the lacking elements. According to the results of a potassium fertilizer experiment in a farmer's field near Singamerta Substation, in which the 60 kg P_2O_5/ha plot gave a grain yield of 4,580 kg/ha and a plant uptake of 42 kg P_2O_5/ha, consisting of 33 kg in grain and 9 kg in straw, at least about 30 kg P_2O_5/ha of phosphate should be applied to such soils. As phosphorus deficiency is usually more serious in the later stages of growth of rice plants in the soils of this type, it is not necessary to use water soluble phosphate, such as ordinary or triple superphosphate. Ground rock phosphate may be more useful. VAN DER GIESEN (1949) who summarized the results of phosphatic fertilizer experiments in paddy fields in Java before World War II, stated that Ceribon phosphate, which is a tricalcium phosphate derived from bat excrements, was as effective as nearly one half of double superphosphate in the paddy fields of bleached loam. Such findings can apply to the Hydromorphic soils in Singamerta which are derived from dacitic tuff in the northern part of Banten and where the residual effect of the rock phosphate was higher than its initial effect on the first crop.

3. Dark Gray Grumusols

The sampling site of Demak soil is an area of Dark Gray Grumusols in the soil map of Central Java. As compared with the Grumusol from Ngale, Ngawi, East Java, Demak soil has a slightly smaller cation exchange capacity, nearly the same clay content, hence a slightly smaller ratio of CEC/clay, higher content of exchangeable calcium and calcium carbonate, lower volume in water, and a slightly higher free iron content. Grumusols of both regions contain montmorillonite as main component of clay minerals, and in addition Demak soil contains a kaolinite mineral and a little quartz. Total phosphorus content of 120 mg P_2O_5/100 g is considered to be comparatively high as is the phosphate sorption coefficient of 2500, although the coefficient measured in a diluted phosphate solution was not as high as that of Andosols. However, the soil for the experiment 3 (a) was not exactly the same as the soil described in Chapter II (No. 5 soil). Since No. 5 soil was collected from a phosphate fertilized paddy field where rice plants were growing, it was not a phosphorus deficient soil, as indicated by the extracting values of available P, P uptake by rice seedlings and a total phosphorus content of 150 mg P_2O_5/100 g.

Total phosphorus contents of Grumusols in the Demak area range from 100 to 180 mg P_2O_5/100 g. Judging from the increase in tiller number in the -P plot of the Demak soil, as illustrated in Fig. 24, the soil phosphorus did not become available until the 5th week after transplanting and only a little became available up to the 10th week. Therefore, in such Grumusols phosphorus should be supplied to the plants during the early stages of growth. Since rice plants require about 10 kg P_2O_5/ha up to the flower primordia stage, rice requirement can be met by application of 20 kg P_2O_5/ha using ordinary or triple superphosphate.

Among the Ngale soils, No. 7 soil was collected for experiment 3 (b) from a paddy field, where fertilizer was applied every season, No. 8 soil from a cassava field without annual fertilizer application, and the total phosphorus content was 128 mg and 114 mg P_2O_5/100 g, respectively. The former soil had a higher content in total soluble inorganic phosphate and the extracting P values obtained by various soil testing methods were higher than those of the latter soil, indicating a clear difference between soil with and without phosphate application. These facts suggest that such Grumusols have a moderate phosphorus supplying ability though they contain considerable amounts of total phosphorus. The presence of a very high phosphate sorption coefficient in a Grumusol is caused mainly by the content in exchangeable calcium and calcium carbonate and partly by that of free iron and aluminum oxides. When the soil is equilibrated with a low P concentration solution, it shows moderate phosphate sorption capacity, indicating that the soil does not have a high sorbing ability for the phosphate applied. Therefore, it can be concluded that the soil does not have a very high primary phosphatic fertility and the effect of phosphate application on the plants grown on such soil is significant. As shown in Table 19, the removal of phosphorus by a crop to produce grain is about 30 kg P_2O_5/ha, and it can be expected that soil phosphorus becomes available in the later stages of growth as mentioned in the case of the Grumusol from the Demak area. Therefore in the Grumusols of the Ngale area 20-30 kg P_2O_5/ha should be applied in addition to nitrogen and sulfur.

4. Red-Yellow Podzolic soils

Red-Yellow Podzolic soils are widely distributed on the moderately undulating hills and terraces in the Lampung Province of southern Sumatra. Under similar climatic conditions, Reddish Brown Latosols have developed in West Java. The formation of these Podzolic soils in this area can be attributed to the presence of silicic parent materials which are poor in iron and bases (DRIESSEN et al., 1974; KYUMA, 1969).

The Tamanbogo Substation of CRIA is located in the eastern part of these undulating lands which are covered by Red-Yellow Podzolic soils derived from dacitic tuff. In an experiment on phosphate fertilizers conducted during the dry season 1973, severe

Table 30. pH and total phosphorus contents of Tamanbogo and Tegineneng soils (Red-Yellow Podzolic soils)

Soil	pH	Total P_2O_5 mg/100g	Rice growth
Farmer's field near the Tamanbogo Substation	5.31	42	deficient in P
Field experiment (I) at Tamanbogo	6.20	226	adequate amounts of P
Tamanbogo soil for the pot experiment	6.00	76	deficient in P
Field experiment (II) at Tamanbogo	5.20	94	deficient in P
Tegineneng soil for the pot experiment	6.30	67	deficient in P

Table 31. Critical levels of phosphorus content in rice plant and available phosphorus in soil at maximum tillering stage in Japan and Indonesia

Location	Mean temperature*		% P in plant critical for		Bray II-P mg/100 g soil critical for	
	June	July	tillering	yield	tillering	yield
	°C	°C				
Hokkaido	15.7	20.2	0.35	0.28	20	10
Tohoku	17.7	21.8	0.35	0.20	—	—
Hiroshima	21.1	25.5	—	—	7-9	2-3
Bogor	25.1	25.1	0.15	0.13	2.5	1.5

* Monthly mean temperature of Hokkaido refers to temperature in Sapporo and that of Tohoku refers to temperature in Morioka

phosphorus deficiency was observed in a farmer's paddy field which had been opened recently in a field adjacent to the Substation (SISMIYATI, 1975). In the paddy fields opened in the Tegineneng Center of the Lampung Tani Makmur (rural prosperity) Project during 1974, rice growth was very poor without phosphate application.

However, the experiment 4 (a) carried out at Tamanbogo during the rainy season 1973/74 did not induce a response to phosphate, probably due to previous phosphate applications in that field.

Another experiment (4 (b)) was set up in a newly opened farmer's paddy field located 5 km from the Substation during the rainy season 1974-75. In this experiment marked response to phosphate was observed in the growth and yield of rice plants.

There was a considerable difference between the total phosphorus content of the soil in the first and second experiments: 226 and 42 mg P_2O_5/100 g respectively (Table 30). As mentioned previously, FUJIWARA (1971) stated that no active phosphate could be statistically detected below 50 mg P_2O_5/100 g of total phosphorus content in paddy soils of Southeast Asia. Table 30, which shows the relationship between the total phosphorus contents of some Red-Yellow Podzolic soils and rice responses to phosphate, suggests that the critical values for the presence of active phosphate may be over 50 and within

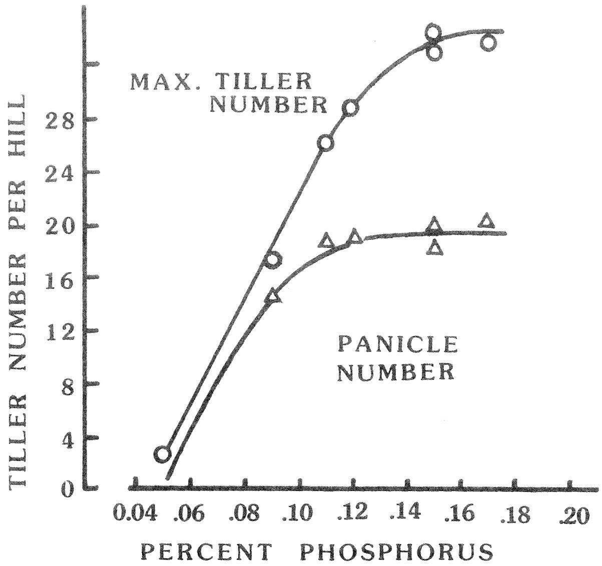

Fig. 30. Phosphorus content in plant at the maximum tillering stage and maximum tiller number, and panicle number

the range of 100 and 200 mg P_2O_5/100 g.

Based on the results of experiment 4 (b) in Tamanbogo, the relationship between the phosphorus content in plants and the maximum tiller number or panicle number is illustrated in Fig. 30. Tiller number tended to increase to a value of 0.15 % P and that of the panicle number up to 0.13 % P. Table 31 compares these values with those obtained in Japan (SHIGA, 1976; SHIGA et al., 1976; HONYA et al., 1965; KOMOTO, 1971). Since the tillering stage of rice in Japan takes place in June and July, monthly mean temperatures of both months were listed, while in the tropics, such as West Java and Lampung, the annual mean temperature of 25.1°C was assumed to be representative because only small fluctuations from this mean occurred. From the Table it appears that high phosphorus content in plants is not essential for tillering under tropical conditions, and that a high concentration of available phosphorus in soil is not necessary to secure such phosphorus content in plants as it is in Japan. These considerations agree with the results obtained from the experiments in Muara, showing that high concentration of available phosphorus in soil is not necessary during the tillering stage.

Red-Yellow Podzolic soils have fertile surface horizons and less fertile subsoil (DRISSEN et al., 1974). When the surface layer is removed by erosion, the subsoil with low fertility is exposed. The various levels of soil phosphatic fertility observed in this region are presumably due to fertilization in the past, and suggest the existence of inherent soil fertility.

As in the case of the Jakenan and Singamerta soils, Tamanbogo soil had a small buffering capacity for salinity increase, as observed in the pot experiment. For example, the electric conductivity of the surface water in the pot without fertilizer application was 200 μmho/cm and the pH was 5.9, whereas in the pot with complete fertilization with NPKS the corresponding values were 4300 μmho/cm and 3.8. In consequence, rice growth in the pots without fertiliztion was better than that in the fertilized pots during a few weeks after transplanting.

In a phosphorus rich paddy field such as that in the first experiment at Tamanbogo 4 (a), an application of 20–40 kg P_2O_5/ha is recommended each season. Also an application of 100 kg P_2O_5/ha is recommended in the case of a newly opened paddy field where the soil available phosphorus content is less than the critical level. In the second season and for the subsequent croppings, the amount of phosphate applied can be reduced gradually to about 30 kg P_2O_5/ha.

As stated earlier, Red-Yellow Podzolic soils have a small buffering capacity. Thus fertilizer doses of nitrogen, potassium or sulfur should be moderate if crops are to respond to those elements.

5. Alluvial soils

Total phosphorus content of Winong soil in experiment 5 (a) was 320 mg P_2O_5/100 g. This is one of the highest values recorded in Indonesian paddy soils. After 2-week incubation at 40 °C, Winong soil produced 17.5 mg P_2O_5/100 g of available phosphorus as determined by the Bray II method. As explained in chapter II, some Alluvial soils are very rich in calcium phosphate and the Bray II method is liable to overestimate the phosphorus availability of such soils. Therefore, although the actual phosphorus availability of Winong soil can be estimated to be lower than the above value, acid reaction of the soil (pH 5.3) suggests that the Ca-P in the soil may be available. It can be concluded that since the soil has a phosphorus availability high enough to sustain rice growth and yield, both in intensity and capacity factors, there is no need to apply phosphorus to this soil.

Since the fertility of Alluvial soils varied with the origin of parent materials, this conclusion should not be applied to all the Alluvial soils. Also it is not necessary to apply phosphate to the soils derived from neutral or basic volcanic ashes, such as No. 9 Regosol which has a high total phosphorus content (210–250 mg P_2O_5/100 g) and high Bray II-P value (25–36 mg P_2O_5/100 g).

IV General discussion

Mechanisms of phosphate sorption

SANCHEZ (1976) considered phosphorus fixation "as the process that alters the availability of phosphate compounds as they are measured by plant growth," and commented that the terms "sorption" and "adsorption" are also used to express the same concept. TISDALE and NELSON (1975) stated that the reduction in the solubility of added phosphates has come to be known as phosphate retention or fixation. Although these two terms are frequently used interchangeably, in the strict sense retention refers to that portion of the phosphorus which is loosely held by the soil and which can generally be extracted with dilute acids; this phosphorus is considered to be largely available to plants. Fixed phosphorus refers to that portion which is not extractable in dilute acids and is generally not considered to be readily available to plants. Webster's Third New International Dictionary explains that the term "sorption" is the result of back-formation by absorption and adsorption, implying a process of sorption by physical or chemical forces or both. In his textbook RUSSELL (1973) adopted the term "sorption" exclusively. Following the Russell's textbook, the authors preferentially use the term "sorption" in the present paper.

It is widely accepted that phosphate sorption by soil occurs at the level of calcium, aluminum or ferric ions bound with negative charges located on the surfaces of clay or humus, the aluminum ions held at the broken edge of clay minerals, and the aluminum and iron oxides or hydroxides films covering the soil particles.

Thus, the relation between the phosphate sorption coefficients measured by the modified methods as well as the ordinary method, and the physical and chemical properties of soils were studied. On the basis of the results obtained, the soils examined were divided into 4 groups depending on their phosphate sorbing mechanisms, as follows:

Group I: As the phosphate sorption coefficients correlated positively with the clay and free iron contents, clay and iron and aluminum oxide films are considered to be the phosphate sorbing bodies in the soils. — Red-Yellow Podzolic soils, Regosols of basic volcanic ash origin, Planosols, Latosol, Gray Hydromorphic soils and Dark Red soils

Group II: Similar phosphate sorbing bodies as in Group I can be assumed to exist, however, the sorbing activity of oxide films is higher than that of Group I. The hydromorphic forming conditions of these soils resulted in a lower crystallinity of oxides and higher phosphate sorption. — Yellow Podzolic soils (Hydromorphic soils) and Regosols of sulfur containing volcanic ash origin

Group III: The fact that the phosphate sorption coefficients are related with the contents in exchangeable calcium, calcium carbonate and the free iron contents, suggests that both forms of calcium are the main phosphate sorbing bodies and oxide films are also related to them to a lesser extent. — Grumusols

Group IV: Relation between the phosphate sorption coefficient, the soluble aluminum content and the organic carbon content indicates that the main phosphate sorbing bodies could be aluminum-humus complexes and the oxide films may also be related to some extent. — Andosols

Some soil properties relating to phosphate sorption, total phosphorus contents and phosphate fertilizer recommendation are presented in Table 32.

Table 32. Soil properties and phosphate fertilizer recommendations

	pH	Clay content %	Total C %	Free Fe %	Soluble Al mg/100g	Iron mobility %	P sorption coeffi-cient	P sorption mecha-nism	Total P content mg P_2O_5 /100g	Fertilizer recommen-dation kg P_2O_5/ha
Red-Yellow Podzolic soil	5.8	34	1.4	2.4	37	8.4	570	I	74	100/20-40
Yellow Podzolic/Gray Hydromorphic soil	5.3	47	1.8	2.2	85	18.3	1500	II	114	30
Dark Gray Grumusol	7.9	83	1.6	1.3	46	5.5	2200	III	143	20-30
Regosol (basic volcanic ash soil)	7.1	8	0.8	1.4	22	4.4	440	I	246	0
Regosol (volcanic ash soil containing sul-furic acid	3.7	16	2.0	2.0	518	33.3	1280	II	139	0
Gray Hydromorphic /Grayish Brown Planosol	5.4	9	0.5	0.4	15	18.3	150	I	39	30
Reddish Brown Latosol	5.7	67	1.6	6.3	47	2.5	1300	I	337	20-30
Andosol	5.8	3	5.9	3.5	525	5.0	2580	IV	365	20-30

Phosphate sorption coefficient and fertilizer application rate

YAMAMOTO et al. (1967) reported that in newly cleared Andosol with low phosphorus availability, application of fused phosphate and ordinary superphosphate at a ratio of 8 : 2 of the amount to reach a coefficient of phosphate sorption of 10 % in the soil, could result in yields of upland field crops similar to those obtained in well fertilized upland fields. Ten percent was an empirical value obtained from the fertilizer experiments. However, HANADA (1973) found that since the maximum adsorption of the monomolecular layer of an Andosol was equal to 12-16 % of the phosphate sorption capacity (or coefficient) at pH 7 and an addition of phosphate over that percentage markedly increased the phosphorus availability the value of 10 % could be theoretically adopted.

In the case of paddy fields, YOSHINO and HONYA (1970) insisted that an amount of available phosphate corresponding to 2 % of the phosphate sorption coefficient of an Andosol was needed to achieve normal growth and yield of rice plants. In this case, available phosphate refers to A-value + fertilizer phosphate applied and A-value can be replaced by 1 % citric-acid soluble phosphate. As a soil usually contains some available phosphorus, the application of phosphorus to reach a coefficient of 1 % of phosphate sorption might be practical and economical (HONYA and YOSHINO, 1965).

The proposal above applies to Andosols in the northern part of Japan. Whether this proposal can be applied to Indonesian paddy soils will be discussed as follows. Red-Yellow Podzolic soils deficient in phosphorus have a phosphate sorption coefficient of 570 on average. Two percent of the coefficient is equivalent to an application of 114 kg P_2O_5/ha, if the amount of soil per ha is assumed to be 1,000 tons. This amount of phosphate is nearly the same as that recorded in the field experiments. Furthermore, an application of 30 kg P_2O_5/ha to No. 10 Planosol also appears to be reasonable. On the other hand an application of 200 kg P_2O_5/ha (which corresponds to 2 % of the phosphate sorption coefficient of a Grumusol deficient in phosphorus) is too high to be practicable.

It is reasonable to consider that a certain level of phosphorus availability will be attained by the application of phosphate to reach a definite saturation degree of the phosphate sorption coefficient which reflects the phosphate sorbing capacity of a soil. Thus a saturation degree of 2 % has been arbitrarily proposed on the basis of the experiments on rice cultivation. As mentioned earlier, however, since the mechanism of phosphate sorption varies from soil to soil, the applicability of the phosphate sorption coefficient also differs with the soils. The range of phosphate concentration for the determination of the phosphate sorption coefficient is markedly different from that in the soil solution even after fertilization. Therefore, such a concept does not seem to be applicable to Indonesian soils in this study, although there is a possibility to determine the appropriate saturation degree on the basis of the data from the field experiments conducted in soils with similar phosphate sorbing mechanisms, and hence similar phosphate sorption coefficients.

Soil testing methods for available phosphorus

Phosphorus uptake by rice seedlings grown in a beaker using each type of soil was assumed to be the standard indicating phosphorus availability of the soil for the evaluation of various soil testing methods.

The equilibrated aqueous solution method was not found to be suitable for paddy soils because the method makes it difficult to maintain anaerobic conditions during the incubation, and the values obtained which placed too much emphasis on the intensity factor were not indicative of the capacity factor.

The extracting values of the resin method, Bray II method or Olsen method applied to air-dried soils were not found to be representative of the phosphorus availability of soils having high iron mobility. This is due to the very high ratios of available phosphorus to total phosphorus reached under the submerged conditions. Therefore, wet soils collected in flooded paddy fields or incubated soils under submerged conditions should be used to determine the phosphorus availability of paddy soils.

Resin method applied to the submerged incubated soils did not improve over- or under-estimated content determined by the extraction of air-dried soils.

On the other hand, the Bray II-P values of submerged soils enabled the successfull evaluation of the phosphorus availability of the paddy soils with a wide range of pH except for the soils rich in calcium phosphate.

As the acidity of Bray II extracting solution is relatively high, the pH must be sufficiently low to hold iron in the solution for the extraction of soils whose pH increased by submergence. However, due to high acidity the diluted acid solution is liable to extract tricalcium phosphate which is originally hardly available.

Applicability of the Olsen method to air-dried soils is superior to that of the Bray II method for proper estimation of the Ca-P rich soils, whereas the applicability of this method to submerged soils is less satisfactory. The addition of EDTA to the extracting solution to keep the solubility of iron compounds in the solution with higher pH, led to the development of the Olsen-EDTA method. With this method, the phosphorus availability of all the soils studied could be evaluated properly except for an Andosol to which fertilizers were applied each year.

The Bray II-P value of 15 *ppm* P, which is the critical level to achieve normal rice growth and yield on a Red-Yellow Podzolic soil was found to correspond to an Olsen-EDTA-P value of 20 *ppm* P, and the latter value was applicable to other soil types.

Phosphate response of rice by soil group

Crop requirement of phosphorus as a nutrient element increases during the tillering and flower primordia stages, which in rice correspond to a period of active growth, leading to the formation of new organs. The higher the phosphorus availability in the soil, the higher the tillering rate and the earlier heading is reached. In the northern part of the temperate zone, where the growing period of rice plants is limited, rice seedlings with high phosphorus content are transplanted in paddy fields whose soil has high available phosphate to overcome the climatic constraint. It has been shown that in years when a cool summer caused delayed growth and crop damage, the Bray II-P value critical for the evaluation of the effect of phosphate application increased up to 200 *ppm* P compared with 100 *ppm* P in ordinary years (SHIGA and YAMAGUCHI, 1976). Since in the tropics there are no seasonal limitations due to temperature fluctuations except for the constraints related the alternation of dry and rainy seasons and changes in day length, phosphate application exerts a comparatively insignificant influence on the promotion of rice growth. Thus within small differences in the maximum tiller number, the effect of phosphate on the yield was not observed although the maximum tillering stage would be reached somewhat earlier. Also the amount of phosphate required to produce a unit weight of rice grain was found to be nearly the same as that for temperate rice, pointing out the importance of phosphorus as a plant nutrient.

Consequently, yield decreases with the decrease in phosphate uptake by plants.

Owing to genetic characteristics such as photoperiodicity, thermosensitivity or basic vegetative growth, rice plants reach a certain growth stage, e.g. tillering, flower primordia or heading, after a certain number of days, and the formation of an organ requires a definite period of time. In consequence, due to the low rate of phosphorus uptake, the organ cannot be developed fully. Thus phosphorus content in the plant and photosynthetic rate of leaves decrease, resulting in yield decrease.

Reddish Brown Latosols in West Java are derived from the mudflow deposits of pyroclastic materials. The values of water soluble-P and Bray II-P are very low but increase slightly after fertilization. Their high phosphate sorbing capacity is ascribed to their high clay and free iron contents. The Bray II-P value hardly increased after submergence and even decreased in some soils, presumably due to the very low reductibility and solubility of iron in soil as suggested by the low iron mobility in proportion to the high free iron content. Just after transplanting, rice plants in the plot without fertilizer showed phosphorus deficiency, whereas the plants in the plot without phosphate application which received nitrogen did not show such symptoms. This indicates that better root development caused by nitrogen application in the soil protected the plants from phosphorus deficiency even without phosphate application. OLSEN et al. (1963) reported that soils with high clay content which show a very low concentration of phosphorus in the soil solution, can tolerate considerably higher rates of phosphorus uptake by plants.

Reddish Brown Latosols in Java are in proximity to **Andosols** at higher altitudes on the volcanoes. According to KAWAGUCHI and KYUMA (unpublished data) three Andosols in Java have a high phosphate sorption coefficient (2500-3000), a total phosphorus content of 450-580 mg P_2O_5/100 g and a very low Bray II-P value of 1 mg P_2O_5/100 g (KITAGAWA et al. 1973, reported data on the clay mineralogy of those soils). TANAKA et al. (1970) stated that in Andosol paddy fields in East Java, rice plants had an appearance suggestive of phosphorus deficiency, although the phosphorus content in the plants was not particularly low. In the tropics where the range of seasonal fluctuation of temperature is small Andosols develop in areas of cooler and wetter climate than latosols. Nevertheless, they have a very high capacity factor for supplying phosphorus even if the intensity factor is low, and severe phosphorus deficiency as seen in Japan is not observed. Therefore, it can be concluded that the amount of phosphate application recommended for the Reddish Brown Latosols would be sufficient for the Andosols of Indonesian paddy fields.

Red-Yellow Podzolic soils which are derived from acid or silicic materials are poor in calcium, magnesium, iron and phosphorus. The free iron content of the soils is half that of Latosols. They have a high iron mobility and when they are incubated under submerged conditions, they give a high iron concentration in the Olsen-EDTA extracting solution. Severe phosphorus deficiency is likely to occur in the newly opened paddy fields converted from upland crop fields or cleared land with Red-Yellow Podzolic soil. The symptoms which consist low tillering, brown spots on the lower leaves and retarded growth, are in agreement with the appearance of phosphorus-deficient-iron-toxic rice plants as described by TADANO (1975, 1976). These symptoms usually disappear after heavy application of phosphates. On the basis of the results of the pot experiments using Tegineneng soil and the experiments in farmer's field in Tamanbogo, the amount of phosphate recommended for such fields was estimated at about 100 kg P_2O_5/ha, with which the critical Bray II-P value of 15 *ppm* P can be maintained in the soil.

TANAKA and NAVACERO (1966) ascribed poor rice growth in acid-sulfate soils to iron-toxicity and recommended liming and heavy dressing of phosphate to correct the disorder. In the case of phosphorus deficiency with iron toxicity observed in the paddy fields on Red-Yellow Podzolic soils, liming might also enhance the effect of phosphate on rice growth.

As the soils belonging to the **Yellow Podzolic/Gray Hydromorphic soil** association and **Gray Hydromorphic/Grayish Brown Planosol** association are derived from materials more acid or more leached than those of Red-Yellow Podzolic soils, they have a lower phosphorus content and higher iron mobility. Jakenan soil, which is a highly leached soil, has a low content of total phosphorus, but it gives a high phosphorus concentration in the soil solution, suggesting that the soil has a very small capacity factor and very large intensity factor for supplying phosphorus. Rice growth was generally poor on this soil and brown discoloration of leaves indicating iron toxicity could be observed even in the plot with complete fertilization. Consequently, growth retardation rate of the plants without phosphate application was relatively small. For this soil, fertilization should include application of phosphorus as well as nitrogen, potassium and sulfur to adjust the nutrient balance. Liming would also be effective in decreasing iron mobility.

The relationship between the Red-Yellow Mediterranean soils on the limestone hills and the **Grumusols** in the lowlands is as follows. The former were formed through a process of laterization while the latter were transformed from the materials transported from the hills. Also neutral or basic volcanic ashes enriched with bases and silica liberated during the process of laterization can be observed in many places in Java (BURINGH, 1968). High phosphate sorption coefficient of Grumusols is mainly due to their high content in exchangeable calcium and calcium carbonate and to some extent to their very high clay content. However, the high phosphate sorption coefficient can not be considered to be the cause of the phosphorus deficiency observed in the soils, since the phosphate sorption capacity of a Grumusol markedly decreased with the decrease in phosphate concentration in the bathing solution used for the determination of the phosphate sorption coefficient. DJOKOSUDARDJO (1974) also reported that in a Grumusol the amount of phosphate sorbed at the site 1, which has the largest sorbing energy among the three phosphate sorbing sites, was very small. Soluble inorganic phosphates of a Grumusol consist of a large portion of aluminum and iron phosphates in addition to calcium phosphate. Solubility of these phosphates in the soil solution must be controlled by the calcium phosphate systems according to the solubility products theory and in general the solubility is very low above pH 7. Therefore, the growth retardation of 5 weeks observed in rice plants grown in the plot with the Grumusol from Demak which did not receive phosphate might be ascribed to the very low solubility of phosphates due to the delay in the decrease of the pH.

CHU et al. (1966) suggested that the low availability of calcium phosphate was due to the low specific surface activity of coarser soil particles, in which most of the calcium phosphate is distributed. This hypothesis is valid since the neutral or basic soils which are particularly rich in calcium phosphate such as the Grumusol from Demak and the Regosol from Yogyakarta have a relatively low phosphorus availability in proportion to their total phosphorus contents. It is conceivable that phosphates in the solid phase of a Grumusol or a soil rich in calcium phosphate are becoming available when the pH becomes lower such as after fertilizer application, submergence or leaching.

Volcanic ejecta deposited as ashfall, pyroclastic flow or mudflow are referred to as **Regosols**, and the materials which are transported by river water and redeposited are classified as **Alluvial soils**. Except for the northwestern region of West Java, almost every volcano has ejected neutral or basic volcanic ashes. Thus, in Java, most of the Regosols and Alluvial soils derived from pyroclastic materials are rich in phosphate, especially calcium phosphate. Phosphate application is not necessary in those soils which have a high content of total and available phosphorus. It should be emphasized that acid extractants such as Bray II solution are liable to overestimate this content in soils rich in calcium phosphate. These considerations do not apply to the Regosols or Alluvial soils of non-volcanic origin.

V Summary

Characteristics of the soils studied

Red-Yellow Podzolic soils (Nos. 1, 2 and 3): They have a pH ranging from 5.5 to 6.3, a soil texture of SCL-LiC, high sand fraction, high water dispersibility of the silt-clay fraction, CEC of 8 meq/100 g, base saturation degree of 32-76 %. Kaolinite predominates in the clay fraction and quartz in the sand fraction. These soils were formed on acid parent materials through both podzolization and laterization under the tropical rain forest climate.

Yellow Podzolic/Gray Hydromorphic soil (No. 4): It has a pH of 5.3, soil texture of HC, CEC of 30 meq/100 g, base saturation degree of 23 % and large volume in water. It contains kaolinite clay minerals with montmorillonite. It was developed on the alluvial deposits derived mainly from acid volcanic ash and is being leached out under the process of ferrolysis.

Gray Hydromorphic/Grayish Brown Planosol (No. 10): It has a pH of 5.4, soil texture of FSL, CEC of 3.8 meq/100 g, high water dispersibility and the lowest volume in water. It consists chiefly of a quartziferous fine sand-silt fraction, and is deficient in N, P, K and S. Montmorillonite is detectable in the clay fraction. Iron mobility is high. This soil developed on the deposits derivd from the acid sedimentary rocks and it is extensively leached.

Dark Gray Grumusols (No. 5, 6, 7 and 8): They have a pH ranging rom 6.9 to 8.4, a soil texture of HC, CEC from 51 to 80 meq/100 g, base saturation ranging from 100 to 150 %, high aggregation ratios and large volume in water. The clay fraction consists of montmorillonite. On the clayey parent materials rich in calcium and magnesium silica and bases originating from hills where laterization has progressed have been added and transformation to montmorillonite has occurred.

Regosols (Nos. 9 and 11): Both soils are derived from pyroclastic materials. No. 9 soil is basic while No. 11 is strongly acid. They have a soil texture of SCL, CEC of 9.6 and 18.6 meq/100 g, which are relatively high in proportion to their clay contents. Their base saturation degree ranges between 87 and 62 %. Both of them contain large amounts of amorphous materials in their clay fraction.

Reddish Brown Latosol (No. 12): This soil has a pH of 5.7, a soil texture of HC, CEC of 17 meq/100 g, base saturation degree of 50 %, high free iron content, and low iron mobility. This soil is derived from neutral andesitic tuffs. Clay particles are aggregated by cementing with iron oxides.

Andosols (No. 13, 14 and 15): They have a pH ranging from 5.4 to 5.9, a soil texture of L-SL, CEC ranging from 25 to 28 meq/100 g, high soluble aluminum and allophane contents. They are humic volcanic ash soils derived from the volcanic ashes of Mt. Iwate.

Gray Lowland soil (No. 16): This soil has a pH of 5.5, a soil texture of LiC, CEC of 16 meq/100 g, base saturation degree of 68 %. It has a complex clay mineral composition and contains large amounts of colored primary minerals. This is a riverine alluvial soil.

Dark Red soils (No. 17 and 18): The soils have a pH ranging from 4.5 to 4.9, a soil texture of SCL, CEC ranging from 6 to 7 meq/100 g and a base saturation degree of 13-22 %. These soils are coarse granular colluvial soils.

Mechanisms of phosphate sorption by soil

The soils studied were divided into four groups according to their phosphate sorption mechanisms which were estimated from the correlation between the phosphate sorption coefficient and various soil parameters.

Group I (Red-Yellow Podzolic soils, Regosols of volcanic ash origin, Grayish Brown Planosols, Reddish Brown Latosols, Gray Lowland soils, Dark Red soils): Phosphate sorption occurs on clay and iron, and aluminum oxide films on the surface of clay.

Group II (Gray Hydromorphic soils, strongly acid Regosols of volcanic ash origin): Phosphate sorption occurs on the same surfaces as those of most of the Group I soils, but the phosphate sorption activity of iron and aluminum oxides is higher.

Group III (Grumusols): Phosphate sorption capacity is primarily attributable to the presence of exchangeable calcium and calcium carbonate and partly to the same mechanisms as those described in Group I soils.

Group IV (Andosols): Phosphate is mainly sorbed by humus-aluminum compounds.

Soil testing methods for available phosphorus

Phosphorus uptake by rice seedlings grown on 100 g of soil in a 200-ml beaker is determined as a standard of the phosphorus supplying ability of the soil.

Equilibrated aqueous solution method: The method is based on water extraction of the submerged incubated soil. Since the intensity factor was only emphasized and not the capacity factor and since it was very difficult to maintain anaerobic conditions during incubation, the method should be improved before it can be applied.

Anion exchange resin method: Resin-P values of air-dried soils were liable to underestimate the P content of soils with high iron mobility and to overestimate that of soils which have a pH above 7 and are rich in calcium phosphate. When the method was applied to a submerged incubated soil, results were not better than those obtained with air-dried soil.

Bray II method: Extracting values of air-dried soils showed a tendency to overestimate the P content of basic soils rich in calcium phosphate and to underestimate that of acid soils with high iron mobility. On the other hand, the extracting values of submerged incubated soils were found to be representative of phosphorus availability of a wide range of soils except for the soils with high calcium phosphate content.

Olsen method: Although the extracting values of air-dried soils underestimated the P content of acid soils with high iron mobility, the method could be applied to soils rich in calcium phosphate. However, there was an overestimation of the P content in Andosols which had received large amounts of fertilizers. When the method was applied to the submerged incubated soils, the same problem arose. EDTA was then added to Olsen's sodium bicarbonate solution and with this extractant almost all the soils examined gave proper values of phosphorus availability except for the highly fertilized Andosols. The last method is referred to as Olsen-EDTA method.

Soil testing for determination of available phosphorus in paddy soils by the Olsen-EDTA method

Four g of air-dried fine soil is put into a test tube (1.5 × 16.5 cm) containing 15 ml of pure water. The test tube is tightly covered with parafilm and incubated at 35°C for 3 weeks. Olsen-EDTA extracting solution consists of 0.5 *M* $NaHCO_3$ solution adjusted to pH 8.5 by NaOH, to which 0.02 *M* EDTA (disodium dihydrogen ethylenediaminetetraacetic acid) is added. For the extraction of submerged incubated soil a 1.23 times concentrated solution is prepared to reach the above concentration at the time of extraction. The soil with water is transferred to a 250-ml polyethylene wide-mouth bottle and rinsed with 65 ml of the concentrated Olsen-EDTA solution. The bottle is closed with double caps and shaken for 30 minutes. The content is filtered and 5 ml of the filtrate is transferred with a pipette into a 25-ml graduated test tube. An aliquot of the solution in the tube is neutralized by a dilute solution of H_2SO_4 until disappearance of the bubbles and then Mo-blue color is developed with the addition of 2.5 ml of Mo-ascorbic-sulfuric acid reagent (JOHN, 1970). After more than 30 minutes, absorbance is read at 710 mμ.

Stock solution: 20 g of ammonium molybdate is dissolved in 300 ml of water. The solution is added slowly with stirring to 450 ml of 10 N sulfuric acid and 100 ml of 0.5 % antimonyl potassium tartarate solution is added to the mixture. The solution is diluted to 1 liter with water.

Mixing reagent: Before use, 1.5 g of L-ascorbic acid is added to 100 ml of the stock solution.

Conversion of Bray II-P value to Olsen-EDTA-P value: A regression equation was made using the values obtained by both methods. With the equation, 15 *ppm* P of Bray II value, which is the critical value to achieve normal growth and yield at the tillering stage in Red-Yellow Podzolic soils, can be converted to 20 *ppm* P of the Olsen-EDTA value. The latter value was found to be applicable to the Reddish Brown Latosols.

Effect of phosphate application on the growth and yield of rice plants and fertilizer recommendation

In rice plant nutrition, phosphorus plays an important role in promoting plant growth. However, in the tropics with high temperatures all the year round, such growth promotion is not necessary for achieving high yields and there is no need to increase the concentration of available phosphorus in the soil. Nevertheless, phosphorus uptake by tropical rice per unit yield is nearly the same as that of temperate rice.

Reddish Brown Latosols: Reddish Brown Latosols derived from neutral or basic volcanic ashes in Java have a high content of total phosphorus. As the water soluble P and Bray II-P values were extremely low in the soils, the rice seedlings transplanted in paddy field appeared to be deficient in phosphorus at the early stages of growth, unlike in the fields where nitrogen had been applied. Rice response to phosphate application was distinctly manifested by the increase in the tiller number although differences in yields were not significant. On the basis of the phosphorus uptake, the amount of phosphorus removed by rice grains and the total phosphorus content in the soil, application of 20-30 kg P_2O_5/ha with proper amount of nitrogen would be recommended for paddy fields of this soil type.

This recommendation can be applied to Andosols adjacent to the Reddish Brown Latosols, as these Andosols have a high phosphorus content.

Gray Hydromorphic soils and Grayish Brown Planosols: Gray Hydromorphic soils and Grayish Brown Planosols have generally a low phosphorus content but very high iron mobility, so that they show a high water and available phosphorus concentration. If a soil has a low total phosphorus content, the capacity factor to maintain a proper available phosphorus level in soil is too low and phosphate application would induce high yield. Since potassium and sulfur are deficient besides nitrogen and phosphorus, application of a proper amount of those elements and of about 30 kg P_2O_5/ha is necessary in such soils. Application of ground rock phosphate should also be effective, because the soils are acid and are losing their bases and iron through the process of ferrolysis.

Dark Gray Grumusols: Retarded tillering due to phosphorus deficiency was observed for several weeks after transplanting in a paddy field with a Grumusol which is basic and has a considerable amount of total phosphorus. In such soils about 20 kg P_2O_5/ha as ordinary or triple superphosphate should be applied to supply water soluble phosphorus to the plants during that period. As Grumusols in general have a weak phosphate sorbing ability, the effect of phosphate application is readily reflected in the plant growth and yield. Therefore, an application of more than 30 kg P_2O_5/ha is recommended along with the application of nitrogen and sulfur in every cropping season.

Red-Yellow Podzolic soils: Red-Yellow Podzolic soils show wide variations in their contents of total phosphorus and the critical value to reach the level where active phosphorus decreases to nearly nil is relatively high. Therefore, sometimes severe phosphorus deficiency can be observed in soil containing more than 100 mg P_2O_5/100 g of total phosphorus. It is concluded from the results of pot and field experiments that the critical phosphorus content in plants at the tillering stage to achieve normal yield amounts to 0.15 % P and the critical Bray II-P value corresponding to the above is 15 *ppm* P. Also it is essential to apply more than 100 kg P_2O_5/ha of phosphate in a newly developed paddy field on Red-Yellow Podzolic soil and in paddy fields where the effect of phosphate is not well defined 20 to 40 kg P_2O_5/ha should be applied.

Alluvial soils and Regosols: Many Alluvial soils and Regosols derived from neutral or basic volcanic ashes have high total phosphorus contents and high Bray II-P values. It is not necessary to apply phosphate to paddy fields with such soils.

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