TARC Notes

Phosphate sorption by Indonesian paddy soils

The process of decrease in solubility or availability of phosphates added to soil has been referred to as phosphate retention, fixation or sorption which implies the participation of both adsorption and absorption mechanisms. So far, it is believed that the process involves the reaction of phosphates with iron, aluminum, calcium and clay in soil. To compare the phosphate sorbing capacity of soils, the phosphate sorption coefficient has been routinely determined in soil laboratories in Japan, as the coefficient obviously enables to discriminate an andosol from other soils by its extremely high value$^{6)}$.

The phosphate sorption coefficient is represented by the amount of phosphate sorbed by a 50 g soil sample bathing for 24 hrs in 100 ml solution of 2.5% ammonium phosphate, $(NH_4)_2HPO_4$, adjusted to pH 7.0 by phosphoric acid, with intermittent hand shaking. The amount is expressed as mg of P_2O_5 per 100 g of an oven-dry soil$^{10)}$. In this paper, the phosphate sorption coefficients of some Indonesian and Japanese paddy soils were correlated with several soil properties to estimate the possible mechanisms of phosphate sorption by different types of soils.

Indonesian soil samples Nos. 1, 2 and 3 consisted of red-yellow podzolic soils; No. 4 was a yellow podzolic/gray hydromorphic soil; Nos. 5, 6, 7 and 8 were dark gray grumusols; No. 9 was an alkaline grayish brown regosol of volcanic origin; No. 10 was a gray hydromorphic/grayish brown planosol; No. 11 was a strongly acid gray regosol/lithosol of volcanic origin; No. 12 was a reddish brown latosol. Japanese soil samples Nos. 13, 14 and 15 consisted of andosols from Iwate; No. 16 was a gray lowland soil from Ibaraki; Nos. 17 and 18 were surface and subsoil of a dark red soil from Okinawa. A study on the phosphorus availability of those soils was presented in the previous report$^{8)}$.

Clay content was determined by the sodium hexametaphosphate-pipette method. Free iron was extracted by the dithionite-EDTA method as described by Asami and Kumada$^{10)}$. Soluble Al was extracted by acetate buffer (pH 4.0) and its content was measured by the aluminon method$^{3)}$. Cation exchange capacity (CEC) was determined by the neutral NH_4OAc method and exchangeable cations were measured on acetate leachate by the atomic absorption method$^{3)}$. Organic and inorganic carbon contents were determined by the acid dichromate oxidation method as described by Kosaka, Honda and Iseki$^{3)}$.

The relation between the P sorption coefficient and clay content in soil is shown in Fig. 1. The CEC/clay ratios of the Nos. 9 and 11 regosols 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. An average CEC/clay ratio of non-volcanic soils, 0.48, was applied to both soils to calculate the corrected clay contents which were 20.0 and 38.8% for Nos. 9 and 11, respectively, as plotted in Fig. 1.

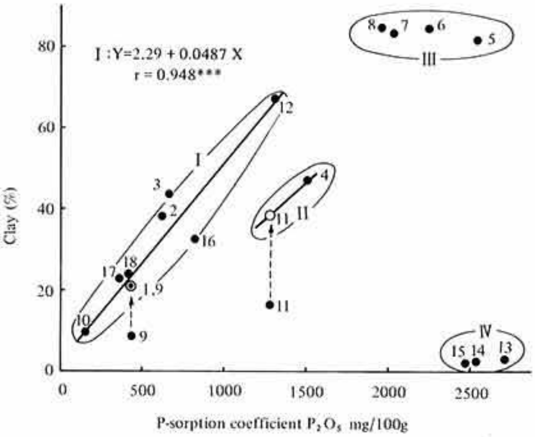

Fig. 1. Relation between the P sorption coefficient and clay content in soil (○ indicates the corrected clay content)

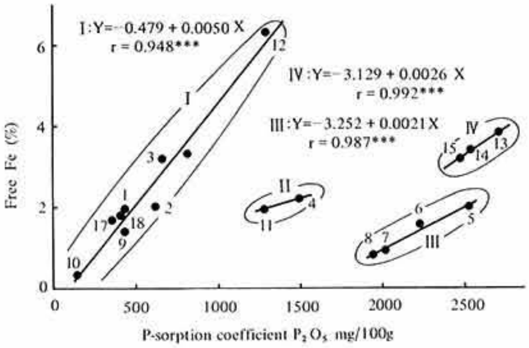

Fig. 2. Relation between the P sorption coefficient and free iron content in soil

As shown in Fig. 1, the soils could be divided into 4 groups. Positive correlation was observed for the group I soils. 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 of the group III soils were grumusols with high clay contents and large coefficients, but relation between both parameters was not proportional. As for the group IV andosols, clay did not play any significant role in the process of P sorption.

In Fig. 2, a positive correlation between the free iron content and the coefficient could be demonstrated for all the groups, although the gradient and position of regression lines varied depending on the groups.

Inorganic carbon contents of the grumusols Nos. 5, 6, 7 and 8 were 0.61, 0.16, 0.02 and 0.03%, respectively. The inorganic carbon was assumed to be derived from $CaCO_3$ and was added to the exchangeable calcium. As shown in Fig. 3, the P sorption coefficient of group III grumusols increased proportionally to the amounts of exchangeable and carbonate calcium, accounting for their very high coefficients.

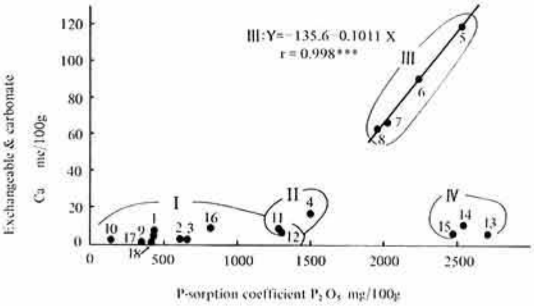

Fig. 3. Relation between the P sorption coefficient and exchangeable and carbonate calcium in soil

As seen from the definition of P sorption coefficient, the larger the amount of phosphate sorbed by a soil, the smaller the phosphate concentration in the solution equilibrated with the soil, suggesting that P sorption capacity for the soil of high coefficient, such as andosol, might be relatively underestimated. Honya and Yoshino[2] revealed that the P sorption reaction ranging from 10 to 10,000 ppm P in the equilibrated solution follows Freundlich's adsorption isotherm, $x=KC^{1/n}$, in which x is the amount of P (mg) sorbed by 1 g of soil, C is P (ppm) in equilibrated solution 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 P sorption capacity at a certain P concentration in the equilibrated solution. For andosols, such coefficient at high P concentration may be more representative as compared with the ordinary P sorption coefficient. Then, in addition to the ordinary P sorption coefficient determined with 2.5% ammonium phosphate solution, the P sorbing capacity was also evaluated by using 0.25 and

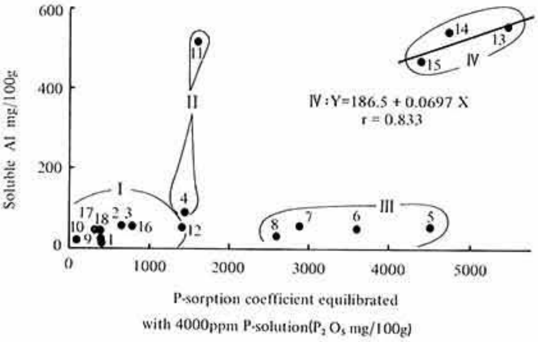

Fig. 4. Relation between the P sorption coefficient equilibrated with 4000 ppm P solution and soluble aluminum

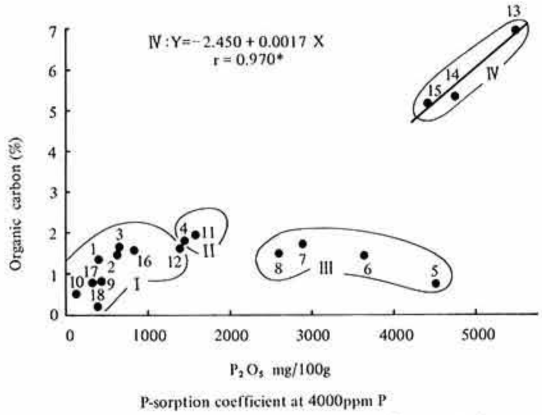

Fig. 5. Relation between the P sorption coefficient at 4000 ppm P and the organic carbon content

0.025% solution to draw the regression line, $\log x = \log K + (1/n)\log C$. With this equation the P sorption coefficient of C at 4000 ppm P was calculated for each soil, as the P concentration in the equilibrated solution for soil of moderate coefficient (about 1000) is approximately 4000 ppm P.

In Fig. 4, the Al contents soluble in acetate buffer at pH 4 were plotted against the calculated coefficients. Three andosols, Nos. 13, 14 and 15, showed positive correlation between them, although the correlation coefficient was not high enough to be significant. A similar trend was observed between the P sorption coefficient at 4000 ppm P and organic carbon content in andosols, as shown in Fig. 5. Close relation between both parameters was reported by Kato on andosols in Japan[5] and by Bezama and Aomine on andosols in Chile[1]. Yoshida and Miyauchi showed that Fe and Al coordinately bound with humus, allophanic Al and free Fe and Al oxide gel are the origin of P sorption capacity in an andosol[11]. Extremely high P sorption coefficients of andosols can be attributed to their very high soluble Al contents. This can not be applied to No. 11 regosol as its coefficient is not as high as its soluble Al content. Possible explanation is that the low pH of No. 11 soil due to the presence of sulfuric acid hinders the sorption of phosphate by soil.

Soils other than the andosols and acid regosol gave no indication to assume that the P sorption is related to the presence of soluble Al. Study on the phosphate sorption of South Brazilian acid tropical soils showed that the sorption of added P was always better correlated with the Al parameters such as exchangeable, oxalate and citrate-dithionite-bicarbonate soluble Al than with the Fe parameters[9]. Another study on the inorganic P fractionation in Indonesia revealed that the phosphate sorbed by soil was found mostly in Al-P fraction followed by Fe-P fraction[7]. As all the soils examined showed that their P sorption was somehow related to free Fe content, it is natural to consider that the P sorption of these soils bore some relation with aluminum components in the soils, although the soluble Al content failed to illustrate apparently the relation with P sorption for the soils of group I, II and III, as shown in Fig. 4. 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 P sorbed by a soil equilibrated with 1 ppm P solution. From the value of K,

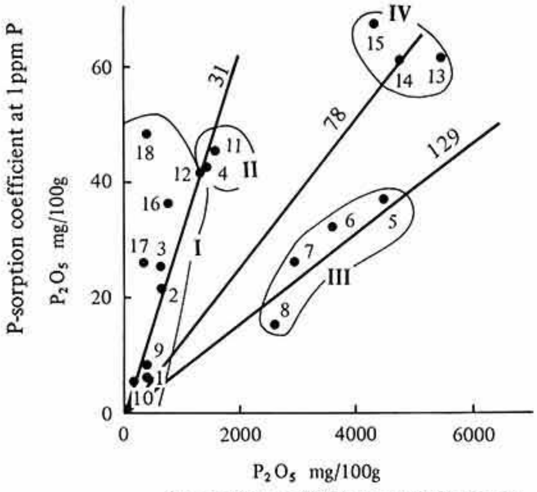

Fig. 6. Relation between the P sorption coefficient at 1 ppm P and 4000 ppm P (each line shows P. S. C. 4000/P. S. C. 1 ratio)

the P sorption coefficients at 1 ppm P were calculated and plotted against the P sorption coefficients at 4000 ppm P, as shown in Fig. 6. The ordinary P sorption coefficients for 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 are different.

On the average, ratio of P sorption coefficient at 4000 ppm P to that at 1 ppm P was 61. The average ratio for the grumusols (group III) was 129, for andosols (group IV) 78, and for the groups I and II 31. Large reduction rate in the amount of phosphate sorbed by a grumusol parallel to 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 very high P sorption coefficient.

The following conclusions were drawn from the relation between P sorption coefficients and several soil properties. P sorption coefficients of group I soils, which included red-yellow podzolic soils, a regosol of volcanic origin, a gray hydromorphic/yellowish brown planosol, a reddish brown latosol, a gray lowland soil and dark red soils, correlated with clay and free iron contents, suggesting that the aluminum and iron oxides coating on clay particles were responsible for the phosphate sorption. Group II soils consisting of a yellow podzolic/gray hydromorphic soil and a strongly acid regosol of volcanic origin showed a pattern similar to that of group I, although their coefficient was higher in proportion to clay or free iron contents. This may be due to the fact that the ability of P 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[4,8]. Soils of group III were dark gray grumusols. Their high P sorption coefficients were primarily attributed to their high exchangeable and carbonate calcium contents, and partly associated with aluminum and iron oxides coating on the clay. Extremely high P sorption coefficients of andosols (group IV) showed a correlation to the carbon, soluble Al and free Fe contents, indicating that the aluminum and iron combined with humus are the main sources of P sorbing capacity of these soils.

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Received for publication, December 27, 1978.

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