EFFICIENT LEVEL OF PHOSPHORUS FERTILITY IN PADDY SOILS

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Differences in effect of phosphate application on lowland rice in various soils

Generally, phosphate application to lowland rice is not so effective in increasing grain yield. Hirano (1958) reported that the relative grain yield of lowland rice without phosphate fertilizer to the one with phosphate fertilizer was 95% as an average of about one thousand three-element experiments in the fields throughout Japan while 69% for wheat or barley (Table 1). In a long-term field experiment carried out at Hiroshima Prefectural Experiment Station located in southwestern Japan, the decrease of relative grain yield of lowland rice in the plot without phosphate application for 40 years was slow as compared with that of wheat which was the winter crop in the same field (Fig. 1) (Komoto, 1977). These results indicate that the availability of phosphorus in the soils is higher under flooded conditions than under upland conditions.

Table 1 Relative yields of two crops in Japan with and without addition of phosphate fertilizer (Kawasaki, 1953)

Crops	NPK	NK	No. of experiments
Lowland rice	100	95	1,161 - 1,187
Wheat or barley	100	69	822 - 841

However, when the phosphorus supplying capacity of soils is not enough to support a normal growth of rice plants in a region, grain yield decreases. For example, in the long-term experiment in Hiroshima Prefecture described above, in which total phosphorus content of the soil had dropped from an initial level of 302 ppm P to 152 ppm, the relative grain yield of rice plants in the plot without phosphate application had decreased to an average of 85% in the last 13 years (Komoto *et al.*, 1979). While in the same kind of experiment carried out at Shiga Prefectural Agricultural Experiment Station, the trend of decrease in grain yield without phosphate application was much more evident (Fig. 2) (Matsuo *et al.*, 1979).

In Hokkaido which is located in a cool region of Japan and where high phosphorus content of rice plants is needed to accelerate tillering in the early stage of growth, the relative grain yield in the plot without phosphate application has been 79% as compared with the three-element plot on an average for 40 years (Fig. 3) (Yamaguchi *et al.*, 1963). Furthermore, the average yield of rice in cool summer years dropped to 45% (Table 2).

It is well known that phosphorus deficiency of lowland rice is severe in the fields newly reclaimed on volcanic ash soils which have strong phosphate absorbing power in Japan, so that heavy application of phosphate fertilizer is needed to obtain ordinary level of grain yield (Honya,

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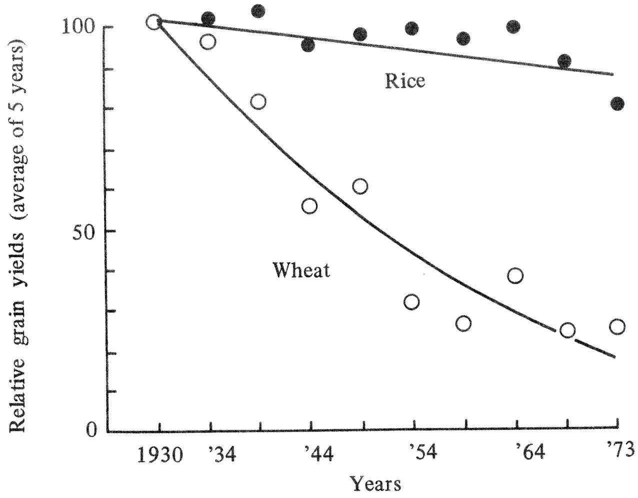

Fig. 1 Relative grain yields of rice and wheat with and without phosphate application in Hiroshima Prefecture. (Komoto, 1977).

Table 2 Relative yields of lowland rice with and without addition of phosphate fertilizer under various weather conditions in a cool region for 41 years (Yamaguchi *et al.*, 1963)

Weather	NPK	NK
Warm summer years	100	77
Ordinary summer years	100	83
Cool summer years	100	45

1961).

In the tropical regions, it was also pointed out that phosphorus deficiency is widespread in the Vertisols, Ultisols, Oxisols, and in coastal alluvial soils, as well as in acid sulfate soils (Goswami and Banerjee, 1978).

Thus the requirement of phosphorus fertilizer of rice plants varies depending on the phosphorus supplying capacity, absorbing ability of soils or climate. Therefore, it is necessary to estimate the phosphorus availability of soils under flooded conditions to determine whether phosphate application is needed for rice plants.

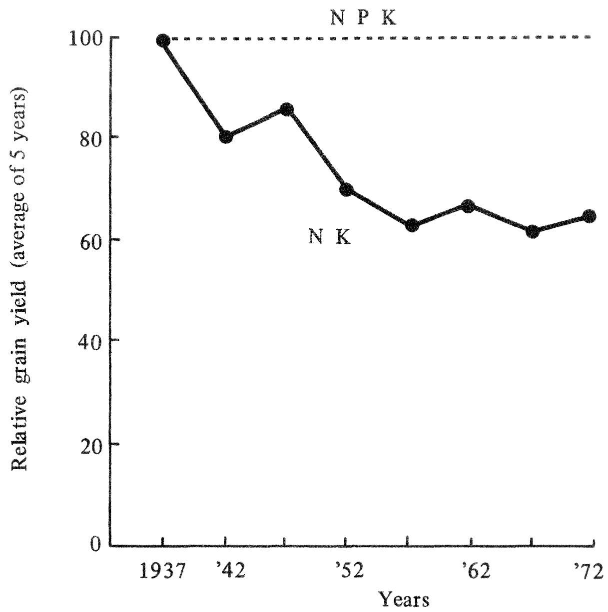

Fig. 2 Relative grain yields of lowland rice with and without phosphate application in long-term field experiments in Shiga Prefecture. (Matsuo *et al.*, 1979).

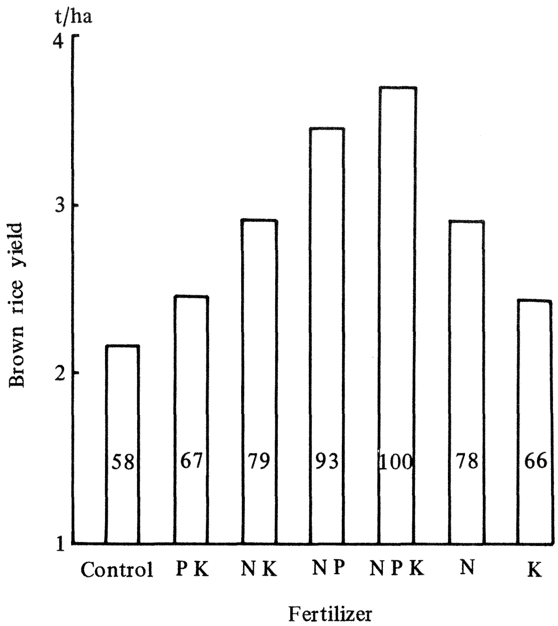

Fig. 3 Average grain yields of rice in the fertilizer experiment for 41 years in Hokkaido. (Yamaguchi *et al.*, 1963).

Measurement of phosphorus supplying capacity of paddy soils

Availability of soil phosphorus changes under flooded conditions, due to the development of reduction of soils. There are changes in the form of phosphate compound, pH, concentration of ion related to the solubility of phosphate in solution, etc. Many of the soil test methods which have been commonly used for upland soils are inadequate as indicator of the phosphorus supplying capacity of paddy soils for lowland rice.

Correlation coefficients between the phosphorus uptake by rice plants under various conditions and the amounts of phosphorus extracted with seven soil test solutions from submerged or air-dried soils including alluvial, peat and volcanic ash soils located in Hokkaido, are indicated in Table 3 (Shiga, 1979). Correlation between the phosphorus uptake from the flooded soils and

Table 3 Correlation coefficients between the phosphorus uptake by rice plants and the amounts of phosphorus extracted with soil test solutions

Conditions of rice cultivation	Pot culture under flooded conditions		Seeding test in beaker under flooded conditions		Seeding test in beaker under upland conditions
Soil conditions at the time of extraction	Air-dried	Flooded †	Air-dried	Flooded †	Air-dried
N/5 HCl	0.33	0.83***	0.25	0.57	0.49
Bray No. 2 *	0.59*	0.90***	0.35	0.71**	0.73**
2.5% acetic acid	0.61*	0.82***	0.37	0.91***	0.84***
Truog	0.66*	0.79**	0.37	0.75**	0.87***
Bray No. 1	0.56	0.64*	0.30	0.68*	0.79**
Morgan	0.73**	0.61*	0.66	0.73**	0.78**
Olsen	0.77**	0.58	0.52	0.43	0.90***
Equilibrium [P]	0.27	0.41	0.33	0.69*	0.66*
log [P]	0.57	0.60*	0.55	0.90***	0.74***

† Flooded at 30°C for 30 days. * soil : solution = 1 : 10

the amounts of phosphorus extracted from the air-dried soils were not so high except for those extracted by the Olsen and Morgan method in the pot experiment in which the correlation coefficients were 0.77 and 0.73, respectively. However, these correlations were clearly improved when an extracting solution at low pH was applied to submerged soils and the amount of phosphorus extracted increased clearly in most soils. The highest value of the correlation coefficient was 0.90 with the Bray No. 2 extraction method (ratio of dry soil to solution was 1:10) in the pot experiment and 0.91 with extraction by 2.5% acetic acid in the seedling test.

In the seedling test, larger amounts of phosphorus were taken up under flooded conditions than under upland conditions in the majority of the soils. Correlations between the ratios of the amounts of phosphorus taken up by rice seedling from flooded soils to those taken up from upland soils and the ratios of the amounts of phosphorus extracted from submerged soils to those extracted from air-dried soils were high when diluted acid solutions were used for the extraction (Table 4).

Table 4 Correlation coefficients between the ratios of the amounts of phosphorus taken up from flooded soils to those from upland soils and the ratios of the amounts of phosphorus extracted from flooded soils to those from air-dried soils

Test solutions	Correlation coefficients
N/5 HCl	0.433
Bray No. 2	0.809***
2.5% acetic acid	0.884***
Truog	0.759**
Bray No. 1	0.847***
Morgan	0.076
Olsen	- 0.030
Equilibrium [P]	0.864***

Many experimental results indicate that the increase in the amount of phosphorus extracted by an acidic solution from submerged soil is highly correlated with the amount of ferrous phosphate which increases under flooded conditions (Fig. 4)(Shiga and Yamaguchi, 1977). Mahapatra and Patric (1969) pointed out that water soluble and loosely bound phosphate and calcium phosphate were highly correlated with the amounts of phosphate extracted with Bray No. 2 solution in air dry samples while iron phosphate, calcium phosphate and aluminum phosphate apparently accounted for most of the phosphate extracted under waterlogged condition as indicated in the following equations.

$$Y_1 = 6.495 + 0.664\,x_1 + 1.789\,x_2 + 0.606\,x_4$$

$$Y_2 = 10.589 + 0.508\,x_2 + 0.694\,x_3 + 0.730\,x_4$$

where Y_1 = Bray extractable P from air dry soils

Y_2 = Bray extractable P from waterlogged soils for 2 months

x_1 = Water soluble and loosely bound P

x_2 = Aluminum P

x_3 = Iron P

x_4 = Calcium P

Uwazawa *et al.* (1980) computed the contribution of calcium phosphate, aluminum phosphate and iron phosphate in the soils located in the Tohoku district to the uptake of phosphorus by rice plants under flooded conditions and found that the coefficients indicating the degree of availability were 0.3 to 0.5, 0.1 and 0.5 respectively for the calcium, aluminum and ferric-type phosphate. These results suggest that the methods which enable to evaluate the increase in ferrous phosphate by flooding as well as calcium and aluminum phosphate are effective to estimate the phosphorus supplying capacity of paddy soils located in Japan.

Miyake (1978) also confirmed that Bray No. 2 extraction method of submerged soil showed a significant correlation with the phosphorus uptake by rice seedlings except for the soils with

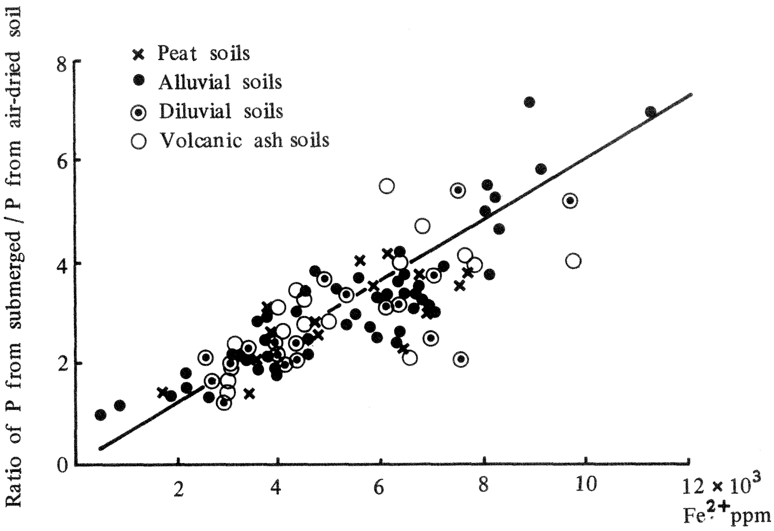

Fig. 4 Relationship between the ratio of extracted phosphorus with Bray No. 2 solution from submerged soils to air-dried soils and the amounts of ferrous iron produced under submerged conditions.

Table 5 Some physical and chemical properties of soils in Indonesia (Miyake, 1978)

No.	Soil	pH (H_2O) 1 : 5	Texture	Total P_2O_5 mg/100g	P sorp. coeff.	Inorg. P fraction ppm P Ca-P	Al-P	Fe-P	Free Fe %	Solu. Al mg/100g	Fe mobility %
1	TG	6.3	SCL	62	440	44	26	24	1.9	11	4.1
2	TB+P	5.5	LiC	82	620	38	73	58	2.0	49	11.6
3	TB–P	5.7	LiC	78	660	36	36	43	3.2	52	9.6
4	SM	5.3	HC	114	1,500	56	49	105	2.2	85	18.3
5	DM	8.4	HC	153	2,530	66	112	101	2.0	53	6.0
6	DP	8.3	HC	178	2,240	105	113	66	1.6	48	2.6
7	NG l	8.0	HC	128	2,020	43	49	36	0.9	54	9.7
8	NG u	6.9	HC	114	1,950	37	19	9	0.8	30	3.8
9	YG	7.1	SL	246	440	411	259	51	1.4	22	4.4
10	JK	5.4	FSL	39	150	52	34	10	0.4	15	18.3
11	PC	3.7	SCL	139	1,280	27	63	114	2.0	518	33.3
12	MU	5.7	HC	337	1,300	18	68	186	6.3	47	2.5
13	KR	5.4	L	262	2,710	32	104	11	3.8	558	2.8
14	TA–P	6.3	SL	248	2,540	20	133	18	3.4	545	3.5
15	TA+P	5.9	SL	584	2,480	42	823	148	3.2	471	8.8
16	KK	5.5	LiC	212	810	25	87	147	3.3	51	3.6
17	MEII	4.9	SCL	161	370	24	74	180	1.7	40	5.7
18	MEIII	4.5	SCL	180	420	18	58	239	1.8	44	0.7

high pH and high calcium phosphate content in Indonesia (Table 5, Fig. 5). Thus, Bray No. 2 extraction method from submerged soils is considered to be suitable for a considerably wider range of soils.

In neutral or alkaline soils, however, the availability of calcium phosphate is low. Bray No. 2 extraction method is likely to overestimate the phosphorus availability of these soils because it extracts well the calcium phosphate accumulated. Miyake indicated that Olsen extraction method, which was recommended by Chang (1976), did not overestimate the available phosphorus in the soils rich in calcium phosphorus but failed to estimate phosphorus availability of soils with high iron mobility under submerged conditions. On the other hand, Olsen-EDTA extraction method of submerged soils, which could prevent re-fixation of phosphate extracted from the soil by ferric hydroxide produced again by oxidation of ferrous iron, was preferable for evaluating phosphorus availability in almost all kinds of paddy soils including alkaline soils throughout Japan and Indonesia except volcanic ash soil to which heavy phosphate fertilizer had been applied (Fig. 6). This method will probably be useful for various soils including acidic and alkaline soils over wide areas. However, this method has not yet been applied in the field.

The values obtained by Bray No. 2 extraction method from submerged soils (Shiga, 1973) were used as indicator of phosphorus availability of paddy soils in this paper, because many experimental results related to plant growth or grain yield in the field have been obtained by using this method.

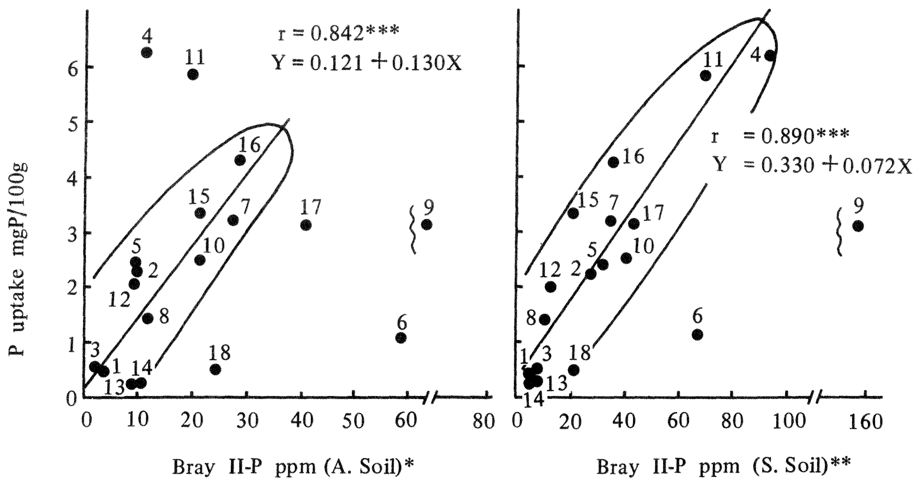

Fig. 5 Correlation between the P uptake by rice seedlings and the Bray II-P value of air-dried(*) or submerged incubated(**) soils. In calculation of the correlation coefficient and regression equation, soils outside of the circle were excluded. Three asterisks(***) of the coefficient indicate 0.1% significance. Those can be applied to other figures. (Miyake, 1978).

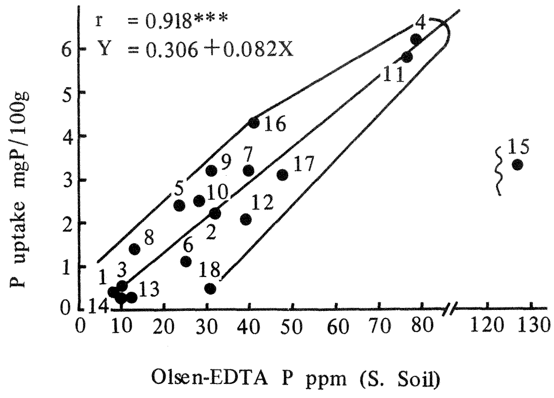

Fig. 6 Correlation between the P uptake by rice seedlings and the Olsen-EDTA-P values of submerged incubated soils. No. 15 soil is a heavily fertilized Andosol sampled at Iwate, Japan. Indonesian Andosol is not found in paddy field. (Miyake, 1978).

Responses of rice plants to different levels of phosphorus fertility in paddy soils

Efficient level of phosphorus fertility for rice production was investigated in field experiments in Hokkaido which is a relatively cool region.

The growth of rice plants on soils with various levels of phosphorus fertility (Fig. 7), following the application of different amounts of phosphorus fertilizer in previous years, is indicated in Fig. 8 (Shiga *et al.*, 1976).

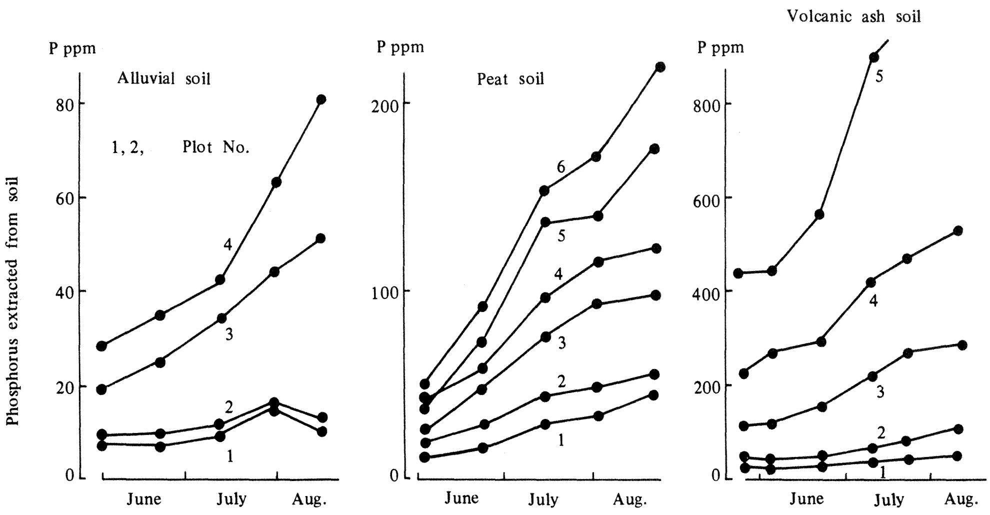

Fig. 7 Amounts of phosphorus extracted with Bray No. 2 solution from various kinds of flooded soils under field conditions.

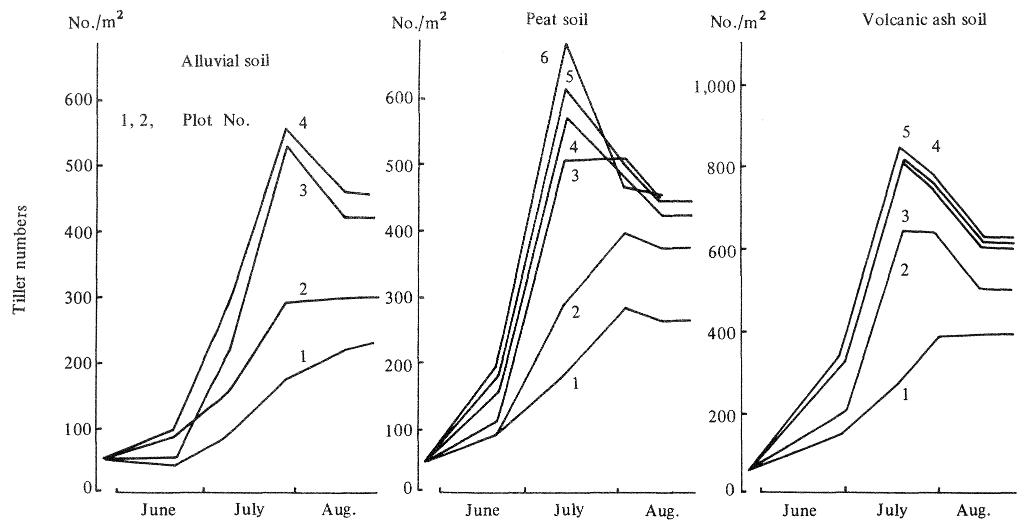

Fig. 8 Rice plant growth on soils with various levels of phosphorus fertility.

Number of tillers in tillering stages corresponded to the amounts of phosphorus extracted with Bray No. 2 solution in three kinds of paddy soils located in places close to each other. The phosphorus contents of rice plants during the tillering stage also could explain well the different growth pattern and indicated relatively stable values in each treatment (Fig. 9).

The relationship between phosphorus contents and tiller numbers was as shown in Fig. 10. The tiller numbers at the maximum tiller number stage increased linearly with the increase in phosphorus contents of rice plants at the same stage until a level of about 0.35% P and gradually

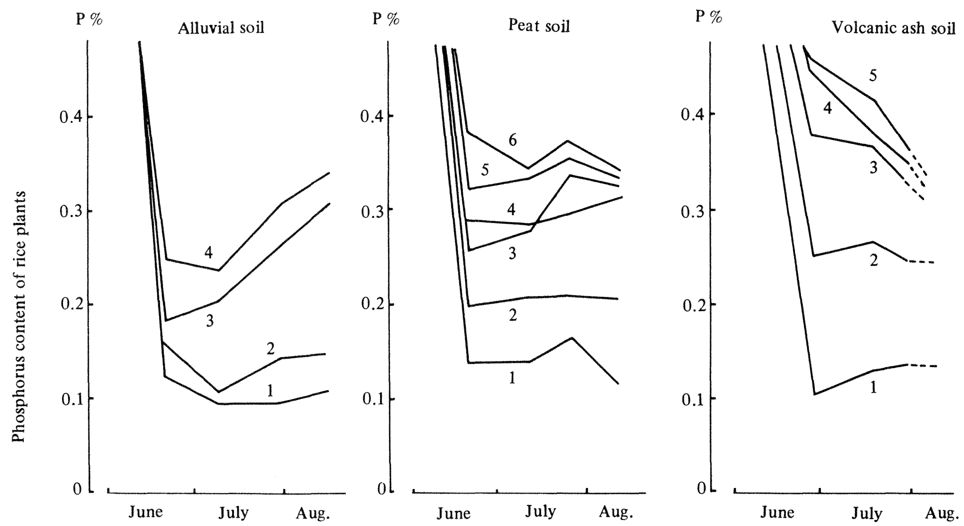

Fig. 9 Changes of phosphorus contents of rice plants growing on soils with various levels of phosphorus fertility.

over 0.35%. However, panicle numbers and grain yields reached the uppermost limits as the phosphorus contents at the maximum tiller number stage reached about 0.26 – 0.30% P (Fig. 11).

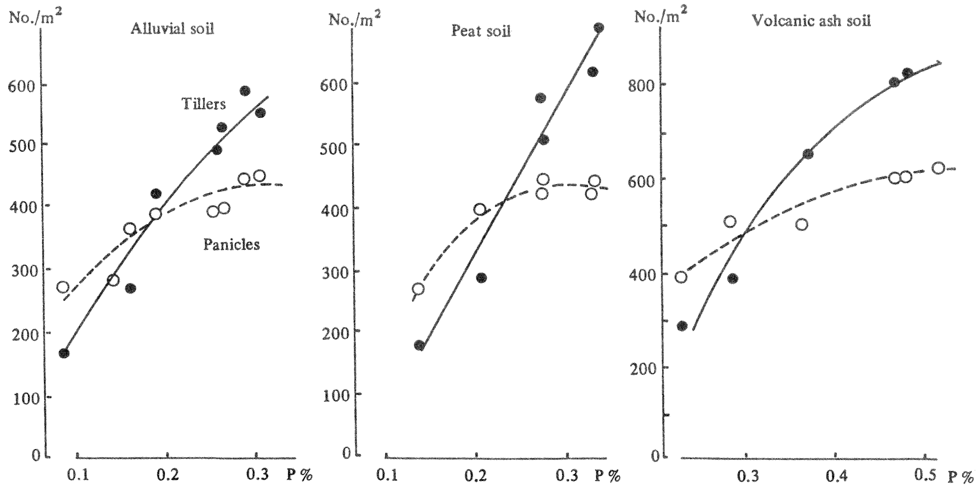

Fig. 10 Relationship between the phosphorus contents of rice plants around the maximum tiller number stage and the tiller numbers at the same stage or the panicle numbers at the final stage of growth.

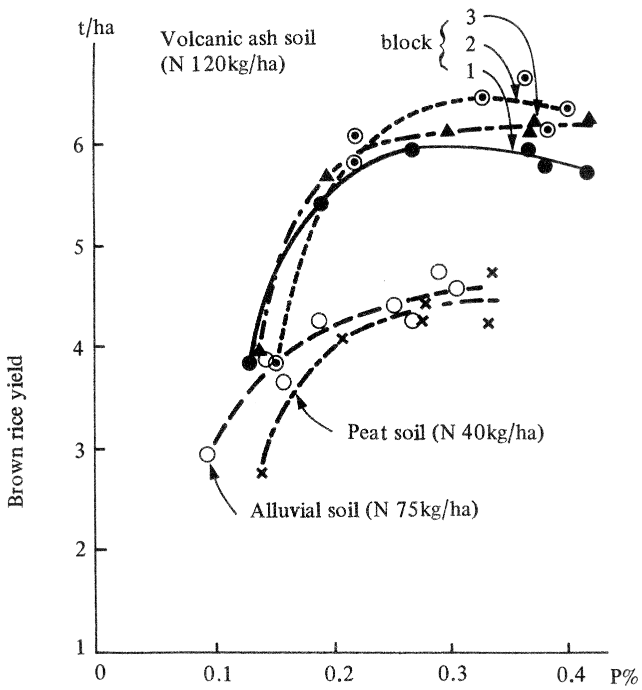

Fig. 11 Relationship between phosphorus contents of rice plants around the maximum tiller number stage and grain yield.

Phosphorus contents of rice plants to obtain the usual level of grain yield should not necessarily be too high under ordinary climatic conditions because the excessive amount of phosphorus is used to increase the number of infertile tillers.

Logarithmic curve was obtained between the phosphorus contents of rice plants and extracted phosphorus with Bray No. 2 solution from flooded soils at the maximum tiller number stage (Fig. 12). Correlation coefficient was 0.89, within the range of a rectilinear relation. It was shown that if the phosphorus contents of rice plants needed for rice production were determined, the values of extractable phosphorus required for the soils could be computed.

The same relationship between phosphorus contents of rice plants and extracted soil phosphorus with Bray No. 2 solution could be observed in other regions with various kinds of soils and different climates (Fig. 13). The majority of the dots were located near the regression curve obtained from the experimental results in Hokkaido.

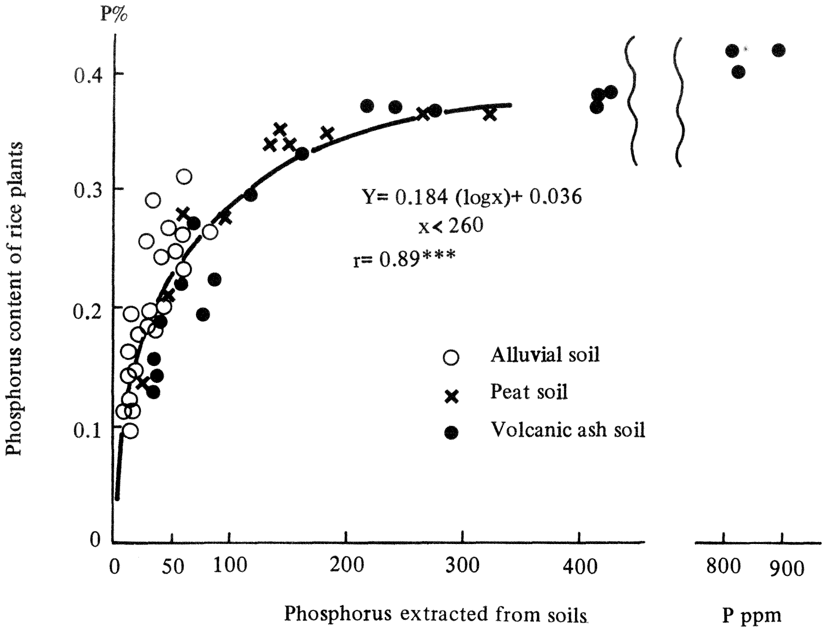

Fig. 12 Relationship between the amounts of phosphorus exracted with Bray No. 2 solution from flooded soils and the phosphorus contents of rice plants around the maximum tiller number stage.

Efficient level of phosphorus fertility of paddy soils for grain yield

In Hokkaido, the phosphorus contents of rice plants around the maximum tiller number stage which are required to obtain an ordinary level of grain yield ranged from 0.26 to 0.30% P on the basis of the results described above (Shiga and Yamaguchi, 1976). Amount of extractable

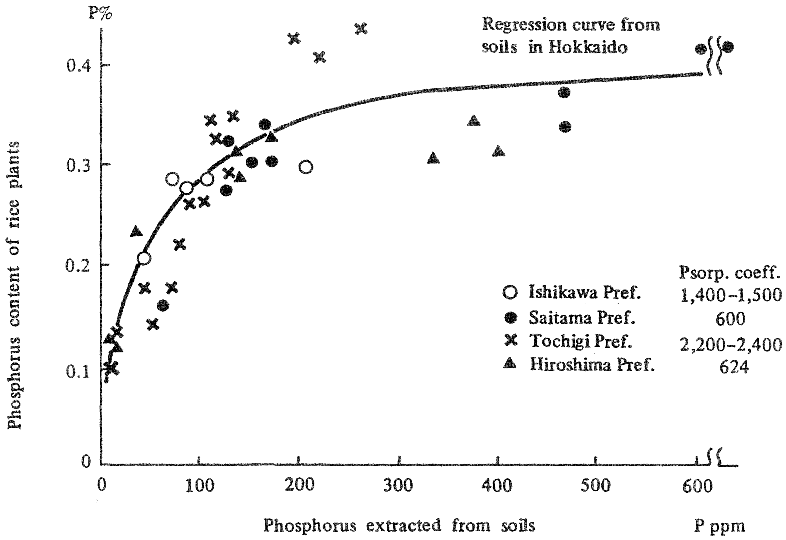

Fig. 13 Relationship between the amounts of phosphorus extracted with Bray No.2 solution from flooded soils and the phosphorus contents of rice plants around the maximum tiller numbers stage in various fields located in different regions of Japan.

phosphorus with Bray No. 2 solution needed to maintain the phosphorus content of rice plants from 0.26 to 0.30% P around the maximum tiller number stage was found to range from 74 to 127 ppm P per dry soil, with an average value of 96 ppm from the regression equation in Fig. 11.

An example in which various amounts of phosphate were applied to the field with varying levels of phosphorus fertility is illustrated with the previous results in Fig. 14. The trend of the increase in grain yield was almost the same in all the results obtained. No response of grain yield to phosphate application occurred in the fields where the value of phosphorus extracted from soils was above 130 ppm. This value did not change when high grain yield amounting to more than 7 ton of brown rice per hectare was obtained by application of additional techniques including larger amounts of fertilizer (Fig. 15) (Shiga and Yamaguchi, 1976). As a result, it was estimated that the efficient level of phosphorus fertility of soils required for obtaining an ordinary or somewhat higher level of grain yield in a cool region is about 100 ppm P on the average, ranging from 74 to 127 ppm, in using Bray No. 2 solution for extractable phosphorus from flooded soils around the maximum tiller number stage. However, in years when the summer is cool, resulting in a delay in rice plant growth, the uppermost limit of grain yield was obtained at a higher phosphorus level, about 170 ppm P (Shiga, 1973). Efficient and safe level of phosphorus contents is estimated to be in the range of 100 – 170 ppm P in soils when the variation of the weather in Hokkaido is considered.

Regional differences in the efficient level of phosphorus fertility

It has been recognized that the phosphorus contents of rice plants at the tillering stage required for obtaining a sufficient number of panicles were lower in warmer regions than in cool regions, so that the efficient level of phosphorus fertility of paddy soils was also lower corresponding to the decrease of phosphorus contents needed by rice plants. Komoto (1977) indicated that the grain yields reached the uppermost limit when the amounts of phosphorus extracted with Bray No. 2 solution from flooded soils were about 22 – 26 ppm P per dry soil

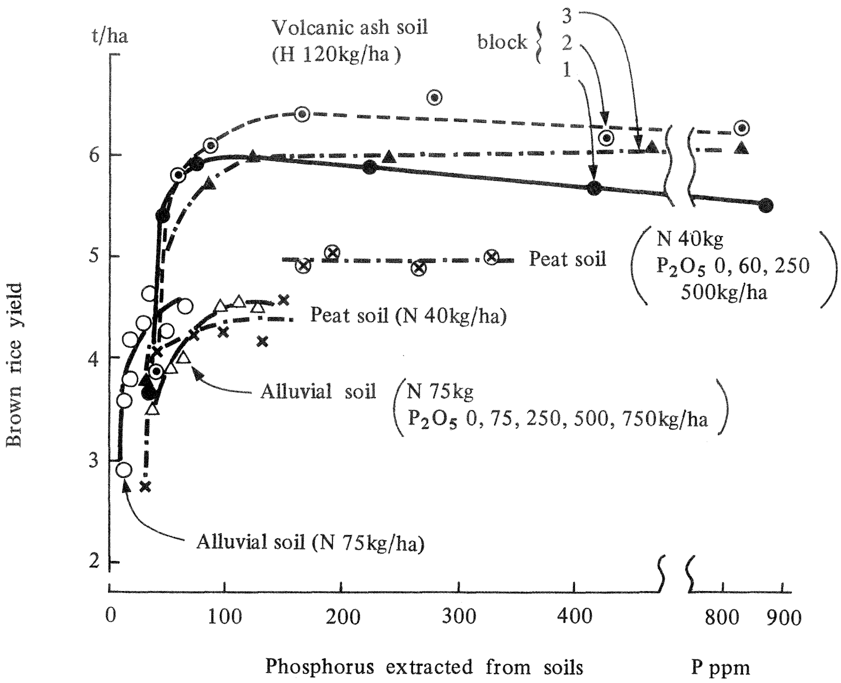

Fig. 14 Relationship between the amounts of phosphorus extracted with Bray No. 2 solution from flooded soils around the maximum tiller number stage and grain yields.

in Hiroshima Prefecture, in southwestern Japan. Miyake, 1980 reported that the phosphorus content of rice plants and the amount of phosphorus in the soils extracted with the same method which is required for obtaining maximum panicle numbers were 0.13% P and 15 ppm P per dry soil respectively in Bogor in Indonesia. In other regions such as Tohoku, Kanto and the Hokuriku district in Japan, these values were found to be intermediate between cool and warm regions. The values are listed in Table 6.

The cause of these phenomena can be explained as follows. In cool regions, where the growing period is limited owing to low temperature in both spring and autumn, the acceleration of rice plant growth due to high contents of phosphorus is effective to obtain a sufficient number of panicles within the range of phosphorus contents described above. While in warmer regions, especially in the tropical regions where growth periods are not limited by low temperature, a sufficient number of panicles can be obtained even though the phosphorus contents of rice plants are relatively low, so that the increase in tiller numbers becomes slow, so long as the amount of phosphorus needed for obtaining adequate panicle numbers is taken up by rice plants (Miyake, 1980).

These results indicate that the required phosphorus contents of rice plants and efficient level of phosphorus fertility of soils vary under different conditions. The values of efficient phosphorus supplying capacity in each region should be determined by using soil test methods adapted to the kinds of soils in considering the growth pattern and the phosphorus contents of rice plants in the regions in order to determine the amount of phosphate to be applied to each soil.

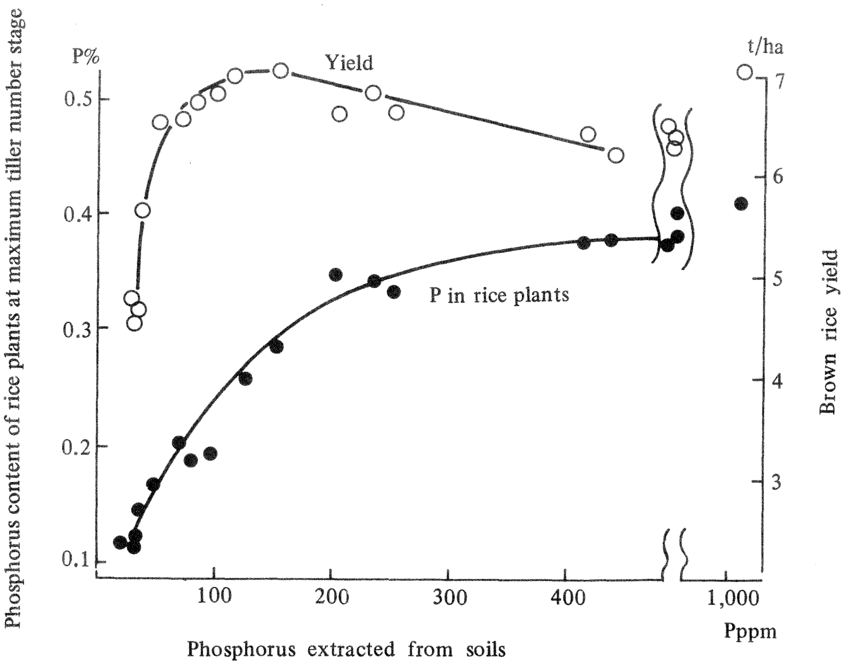

Fig. 15 Relationship between the amounts of phosphorus extracted with Bray No. 2 solution from flooded soils and grain yield in high yielding trial.

Table 6 Comparison of critical levels of phosphorus contents in rice plants and extractable phosphorus in soils with Bray No.2 solution for grain yield at maximum tiller number stage in various regions

Location	Mean temperature		Conditions	P% in rice plants	Pppm in soils	Remarks
	June	July				
Hokkaido	15.7°C	20.2°C	Cool summer	0.35 - 0.40	170	Shiga *et al.* (1976)[16]
			Ordinary summer	0.26 - 0.30	100	Shiga *et al.* (1976)[15]
Tohoku (Iwate Pref.)	17.7	21.8	–	0.20 0.26 (-0.30)	– –	Honya (1961)[5] Chiba *et al.* (1970)[2]
Hokuriku (Ishikawa Pref.)	20.4	24.8	–	0.22 (-0.26)	43(-87)	Ishikawa Pref. (1968)[6]
Kanto (Tochigi Pref.)	19.8	23.6	Early planting	0.26	87	Nakano *et al.* (1970)[13]
Chugoku (Hiroshima Pref.)	21.1	25.5	–	0.13 - 0.20	22 - 26	Komoto *et al.* (1977)[7]
Indonesia (Bogor)	25.1	25.1	–	0.13	15	Miyake (1980)[12]

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