Growth and Yield of Rice Plants in Low Phosphorus Soils

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In Japan's paddy fields there are many cases showing that much phosphorus is supplied from soils and rice yield does not decrease for several years without any application of phosphatic fertilizer probably owing to the accumulation of phosphorus applied as fertilizer for many years in the soils.

According to the data compiled by Kawasaki,[1] the results of NPK response experiments carried out on 1,655 items of rice plants in prefectural agricultural experiment stations in Japan show that the yield index of rice in the non-phosphate plot (P(−)plot) was so high that it reached 95 on an average against 100 in the complete plot.

At the Hiroshima Agricultural Experiment Station experiments have been continued on the application of phosphatic fertilizer for 40 years since 1930 and in the P(−) plot the yield index of rice remains on a level of 88 at present, though the total phosphorus content of plow-layer soil in this plot has decreased to 25 per cent of that in the phosphate plot (P(+)plot).

In this paper the maintenance of such a high level of rice yield in a low-phosphorus paddy field is discussed from the angles of the character of the soil and the characteristic of the rice plant.

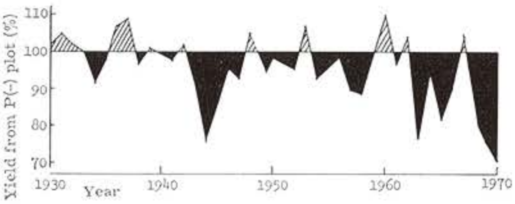

Fig. 1. Transition of rice yield of P(−) plot as percentage of yield of P(+) plot

Availability of phosphorus in soils

It is a well-known fact that phosphorus is contained in soils in such forms as calcium phosphate, iron phosphate, aluminum phosphate and organic phosphate, etc. Rice plants are generally grown in water-logged conditions which cause the reduction of soils. Under such conditions, ferric phosphate is reduced to ferrous phosphate and the solubility of phosphorus is increased.

In addition, the pH of soil is raised and the availability of phosphorus is increased by hydrolysis. The phosphorus thus made available is mostly retained there and hardly translocated to lower layers of soil, increasingly accumulating in the plow-layer. A fairly large amount of available phosphorus, however, is translocated from the plow-layer to lower layers in sandy loam which is low in iron content.[2]

The availability of phosphorus varies with the geological difference of soil and it is lower in volcanic ash soils which show a high silica-alumina ratio while it is higher in mineral, acid alluvial soils which are lower in silica-alumina ratio.

In the eastern or northern parts of Japan, volcanogeneous soils are widely distributed while in the western parts most of the paddy fields are of alluvial mineral soils. Therefore in east or north Japan the effect of phosphorus applied as fertilizer is noticeable.

On the contrary, in west Japan phosphorus can easily be changed into available forms because of the characteristic of soils and due to the high temperature in the first half of the growing period of rice plants, the reduction of soil progresses early and the available phosphate content of soil is increased.

In addition, the reduction of soil is promoted and the change of phosphorus into available forms is accelerated in the presence of much phosphorus in the soil. Under such conditions the application of phosphatic fertilizer is hardly effective.

Phosphorus absorption and growth in rice plants

The absorption of phosphorus by the root of a rice plant has intimate relation to the metabolisms taking place in the plant. Phosphorus is an element which is selectively absorbed by roots from the surrounding medium, and the absorption is apt to be influenced by respiration inhibitors and temperature.[5]

In morphological investigations of rice plants to trace the cause of the low yields in the P(−) plots of the NPK response experiments carried out in north Japan, it was noticed that the main factors reducing the rice yield were decreases in the number of panicles and the percentage of ripened grains, and especially poor ripening in the years of cold-weather damage.[9]

In west Japan the rice yield is maintained on a high level even in low phosphorus soils. The factors for this high yield are analyzed from the viewpoint of rice plant physiology.

1) Rice plants have large phosphorus absorbing capacities and easily increase the number of tillers in west Japan because the temperature is higher there than in north Japan.

2) After heading, the translocation of phosphorus from straw to the ears progresses in the rice plant more smoothly in west Japan than in the cold regions, and a large amount of phosphorus can be translocated from the leaves and stems to the heads. Therefore, phosphorus applied as fertilizer has a comparatively little influence on the ripening of grains.[3]

3) Rice plants in north Japan show a high percentage of phosphorus in the leaves and stems. But they also are high in iron content[4] so it is probable that active phosphorus content is decreased in them.

On the other hand, in north Japan the rice plant is heavier in the weight of grains than that of straw so the grain/straw ratio is not less than 1 there, while the ratio is not more than 1 in west Japan.

This fact means that the amount of phosphorus to be translocated from the leaves and stems to the heads must be larger in the rice plant of north Japan than in that of west Japan and suggests that the occurrence of poor ripening due to a deficiency of phosphorus in the grains may be less frequent in west Japan than in north Japan.

As for the rice productivity of plants showing a low percentage of phosphorus, experimental data obtained by the Hiroshima Agricultural Experiment Station in a field of granitic alluvial soil in west Japan will be mentioned below to give concrete explanations from a viewpoint of the relation between the growth of rice plants and their chemical composition.

In the P(+) plot of the field the total phosphorus content of soil is 140 mg/100 g as P_2O_5 and available phosphate content (determined by Bray No. 2 method) is 60∼90 mg per 100 g of soil under reductive conditions. In contrast to these values, in the P(−) plot total and available phosphate contents are only 34 and 4 mg respectively though the yield of rice still remains on a high level there.

In these experiments, examinations were made on the relation between the growth and the components of chemical composition of the rice plants in the years when the yields of rice were the same in amount in both P(+) and P(−) plots. The results obtained in recent years (Fig. 2) show that the rice

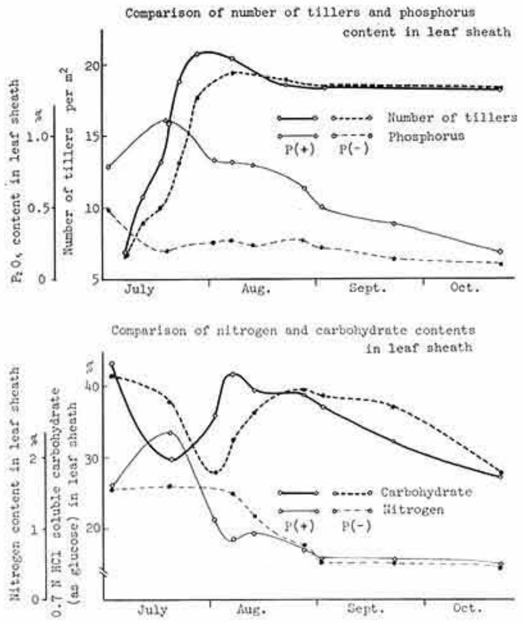

Fig. 2. Difference of P(−) plot from P(+) plot in number of tillers and nitrogen and phosphorus contents of leaf sheath

plants in the P(−) plot have such morphorogical characteristics as follows: the number of tillers is small in the beginning and gradually increases; the maximum tillering stage comes late; the rate of non-bearing tillers is low and the number of panicles is close to that in the P(+) plot.

The phosphorus content of the plant is low until the maximum tillering stage and then increases owing to increases in the amount of roots and the capacity of phosphorus absorption.

In this case available phosphate is not increased so much in amount in the low-phosphorus soils so an increase in the amount of phosphorus absorbed is considered mainly to be attributed to some physiological conditions of the rice plants themselves.

On the other hand, there is a certain relation between the nitrogen and the carbohydrate contents of the rice plants, and nitrogen content is observed to increase later in the P(−) plot than in the P(+) plot.

Carbohydrate content remains on a low level during the stage of high nitrogen content and reaches the peak later in the P(−) plot than in the P(+) plot.[3]

These facts indicate that the turning point from the stage of protein metabolism to that of carbohydrate metabloism comes earlier in the P(+) plot than in the P(−) plot where the stage of protein metabolism lasts longer.

Accordingly, in the P(−) plot the decrease of tillers is small in number and the percentage of ripened grains is almost the same as in the P(+) plot, though the time of heading is a little retarded. Such results are mainly due to the influence of temperature as mentioned above.

Throughout the period of this experiment extending over 40 years, the years, when decreases in yield were clear in the P(−) plot compared with the P(+) plot, were selected to examine the rice plants morphologically, it was found that the bad crops were mainly due to decreases in the number of panicles and poor ripenings were rarely the cause of decreased yields. From this fact, it may safely be said that in west Japan the rice yield does not decrease in general if phosphate in soils is sufficient in amount to insure a necessary number of tillers.

Available phosphate in soils and growth of rice plants

Though there are many methods reported for extracting available phosphate from soils, such a method as giving a highly correlative result with phosphorus absorption by plants is desirable for the purpose.

Therefore, the author adopted the Bray No. 2 method in his experiments because Shiga[8] examined various methods and reported that the availability of phosphorus measured by this method shows highly correlative results with phosphorus absorption by rice plants, increased with the reduction of soils except volcanic ash soils.

When available phosphate content of soil comes to above 15~20 mg per 100 g of soil as P_2O_5, available phosphate cannot act on the rice plants to increase the number of tillers. This value is variable to some extent according to the kind of soil or difference in temperature, being lower in sandy loam and a little higher when the soils contain a high percentage of humus or the temperature is low.

The critical level of the available phosphate content of soil above which phosphate can not act on rice plants to increase the rice yield any more is 5~6 mg (P_2O_5) in reduced soils as shown in Table 1. The total phosphorus content of soil is about 50 mg (P_2O_5) in this case. Rice plants show an initial depression growth type when the available phosphate of soil is below 5 mg.

Table 1. Relation between phosphorus content of plow-layer soils and yield of rice

Plot No.	Total P_2O_5 mg/100 g	Bray No. 2 P_2O_5 mg/100 g	Yield as percentage
1	38	3.6	100
2	40	4.3	123
3	43	4.5	122
4	48	6.8	134
5	57	9.2	132

Soil environment and effect of phosphorus

In granitic alluvial soils the cation exchange capacity (CEC) is generally small and the effect of phosphorus applied as fertilizer on the rice plants is different from that in the soil with a large CEC. The relation between the effect of phosphatic fertilizer and the growth of rice plants according to the difference of CEC in soils is shown in Table 2.

It is seen in this table that an initial increase in the number of tillers is larger in the soil with a small CEC than in the soil with a large CEC. The increase is easy in the soil with a small CEC even if the rice plant contain low percentages of phosphorus. This also may be a factor reducing the manifestation of the effect of phosphorus applied as fertilizer to the alluvial sandy loam.

In the soil with a small CEC the number of tillers is increased by the application of much phosphate but the increase is marked by declines after the maximum tillering stage and the rice yield is rather decreased by an increased application of the phosphatic fertilizer.

On the other hand, in the soil with a large CEC, the growth of rice plants is made vigorous in the latter half of the growing period by the application of phosphate ferti-

Table 2. Relation between phosphorus content of subsoil with different CECs and growth of rice plant

CEC of soil	Amount of P_2O_5 applied kg/are	Total P_2O_5* in soil mg/100 g	Tiller stage		Maturity time				Brown rice yield kg/are
			Number of tillers per m²	P_2O_5 in leaf & stem %	Number of panicles per m²	Bearing tillers as percentage	P_2O_5 in straw %	P_2O_5 in grain %	
	0	32	35	0.32	36	88	0.04	0.32	4.0
5.2**	10	40	90	0.67	175	52	0.10	0.65	36.0
	40	61	113	1.11	179	44	0.22	0.68	33.2
	0	28	35	0.31	38	90	0.04	0.29	5.3
30.8***	10	36	74	0.72	268	67	0.07	0.53	49.3
	40	58	71	1.18	297	68	0.16	0.70	62.9

* Determined after application of phosphatic fertilizer.
** SL, granitic alluvium.
*** Zeolite was added to SL, granite alluvium.

lizer. But in this case it is unthinkable that the CEC of soil directly exerts an important influence upon the behavior of phosphorus, and the above-mentioned effects seem to be due to some other factors symbolized by CEC, as soil texture and others.

The difference in the rice yield between the two kinds of soil is greatly influenced by the amount of nitrogen supplied to the rice plants.[7] In this way, the effect of phosphorus also is variable according to the cooperative factors.

Generally, in Japanese alluvial soils in case the brown rice yield remains on a level of about 5 tons per ha, the amount of available phosphate in soils is enough because soil phosphate is readily made available in the alluvial paddy fields and by high temperature. So, it can not be expected to increase the rice yield only by applying phosphate.

It is believed, however, that a necessary amount of phosphate in soils will be increased, if soil environment is improved and a level of rice yield is raised by the use of more advanced techniques, as fertilization to insure the nutrition of rice plants in the later stage of the growing period, application of organic materials, improvement of the percolation of soils and improvement of intermittent irrigation during the growing period.

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