Reduction of Phosphate Application in Paddy Rice Cultivation for More Sustainable and Environmentally Sound Agriculture

Motoyuki HAGIWARA[1], Shinichi KAWAMURA[2], and Takashi YAMAMOTO[3]

[1] *Faculty of Agriculture, Shinshu University, 8304 Minamiminowa, Nagano, JAPAN*
[2] *Reinan Regional Development Agency, Fukui Prefecture, Obama, Fukui, JAPAN*
[3] *Nagoya Seiraku Co., Nagoya, Aichi, JAPAN*
e-mail : mothagi@shinshu-u.ac.jp

Abstract Heavy application of phosphate (P_2O_5) in paddy rice production has been continued since 1960s in Japan. Although yield was increased and stabilized during that period, recent environmental concerns require minimization of P_2O_5 application. Six-year experiment on the effect of reduced P_2O_5 application on growth and yield of paddy rice was carried out in Andosols area, where heavy P_2O_5 application had been continued. The experiment showed that growth and yield were not significantly influenced by reduced P_2O_5 application and that reduction by 25-50% compared to the present recommended application amount was safely practicable. Input and loss of available P_2O_5 in the soil was estimated to balance when P_2O_5 application is 4.6 kg/10 a. Since available P_2O_5 has been accumulated in the soil, drastic reduction of P_2O_5 application over the long term is possible without causing significant decline in yield and its stability by making most of the accumulated P_2O_5 stock.

Key word : Phosphate, Phosphate Balance, Andosols, Paddy Rice, Growth and Yield, Reduction of Fertilizer Application

Introduction

Phosphate is a major element in plant nutrition. Phosphate rock, a raw material of phosphate fertilizer, is estimated to be exhausted by around the end of this century, if a present consumption rate continues. This fact confronts us with a difficult problem of how crop production can be increased, with saving the consumption of phosphate, in proportion to the increasing demand as a result of continuing world population increase. Although increased phosphate application contributed to a marked production increase of many crops during the latter half of the last century, it gave rise to an environmental problem of water pollution when the level of phosphate input was relatively high. The reduction of phosphate input in agricultural production is now required from a viewpoint of sustainability of agricultural production and environmental conservation.

Andosols (a type of volcanic ash soil) is widely found in Japan. Since typical Andosols called "Kuroboku" soil has a property of high phosphate absorption coefficient, the availability of phosphate in such soil is generally so low as the crop growth and yield to be restrained. From around 1960, increased phosphate application was recommended to improve crop production especially in areas where Andosols is distributed. Heavy phosphate application became wide spread both in upland crops and paddy rice within a couple of decades. In paddy rice production, the spread of heavy phosphate application was accelerated due not only to its effect on the improvement of growth and yield but also to its effect on the alleviation of cool summer damage. Cool summer damage is one of the major constraints of paddy rice yield, and statistically it affects Japan's paddy rice production once in about four to five years. Although water pollution due to heavy phosphate application in paddy field was recognized in some areas from around 1980, recommended amount of phosphate application had not been re-estimated in northern Japan until around

2000. Since phosphate application is more effective in cool than in warm years,[1] heavy input of phosphate for paddy rice production in Japan during the last some 20 years when overproduction of paddy rice continued has been like a practice to get yield insured against cool summer damage rather than a practice to improve yield. However, recent global warming is going to diminish its significance as insurance and is forcing us to reconsider the amount of phosphate application in Andosols areas.

This study aimed at clarifying the effect of reduced phosphate application on paddy rice growth and yield in Andosols area. Response of paddy rice growth and yield grown under various phosphate application levels was investigated in a typical Andosols area. Based on the result, soil fertility management in terms of available phosphate balance in soil was estimated.

Materials and Methods

Experiment was conducted from 2001 to 2006 in the paddy rice field of Education and Research Center of Alpine Field Science, Faculty of Agriculture, Shinshu University. The field is located in Minamiminowa Village, Nagano Prefecture, where Andosols is widely distributed, and the soil type of the field is Andosols. Japonica paddy rice variety Koshihikari was grown under four levels of phosphate application, including conventional level, with equal application of nitrogen and potassium. Fertilizer treatments in each year are shown in Table 1. One plot was 6 m×8 m, and plots were arranged in randomized block with two replications in 2001. The arrangement of plots was fixed throughout the following years.

Four-leaf stage seedlings were hand-transplanted in the manner of three seedlings per hill with hill spacing of 15 cm and row spacing of 30 cm in the middle of May each year. Cultivation management except fertilizer application followed conventional method.

Five average hills were sampled from each plot at around 2-week intervals. The number of tillers, plant height and plant age in leaf number were recorded. Leaf color of a fully expanded uppermost leaf was measured by SAPD-502 (Konica Minolta Co.). Leaf area was determined by using an image scanner and image processing software. Dry weights of leaf, stem plus leaf sheath, and ear were determined after drying at 80°C for three days. Brown rice yield and other yield components in each treatment were determined for 20 hills sampled from each plot at harvesting stage.

Table 1. Fertilizer treatment (kg/10 a).

Year	Treatment			
	Cont.	-1P	-2P	-3P
	Basal dressing except phosphate			
2004-2006	N : 6.0, K : 6.0			
2001-2003	N : 6.0, K : 14.0			
	Basal dressing of phosphate			
2005-2006	21.8	15.8	9.9	4.0
2004	25.3	19.3	13.3	31.3
2001-2003	21.3	19.3	9.3	27.3
	Top dressing			
2004-2006	N : 3.0, P : 0.6, K : 0.6			
2001-2003	N : 4.0, P : 0.8, K : 0.8			

Cont. corresponds to the conventional fertilization practice in the experiment site. Top dressing was applied 10-20 days before heading.

Soil samples for the determination of soil nutrient content were collected from each plot twice every year in April before paddy rice field was submerged and late in September or early in October after harvest. Plant samples collected at harvesting stage were used for phosphate content determination.

Result and Discussion

As for plant height, plant age by leaf number, leaf color and leaf area index, no conspicuous difference was found among treatments throughout six-year experiment. Nitrogen dominates and phosphate influences the number of tillers. Deficiency of phosphate reduces the number of tillers.[2] Although difference in the number of tillers among treatments was found in some cases, it was neither significant nor in parallel with phosphate level throughout six-year experiment.

Table 2. Yield and yield components.

Year, Treatment	No. of panicles	No. of spikelet per panicle	Percent ripened grain	1000 grain weight (g)	Yield (kg/10a)
2003					
Cont.	372	87.1	89.2	22.5	653
-1P	408	90.7	85.3	22.1	702
-2P	366	92.3	87.4	22.3	658
-3P	367	91.2	90.9	22.4	683
2006					
Cont.	464	84.6	90.4	22.1	775
-1P	460	87.9	90.2	22.3	812
-2P	436	90.2	89.8	22.0	778
-3P	418	91.3	91.6	22.0	768

Results of only 2003 and 2006 were shown due to limited space. Significant difference was not found in any of the items. In 2003, -2P was applied with minimum and -3P with the maximum amount of phosphate.

Similarly, leaf area was not significantly different among treatments. Dry matter production in terms of dry weights of leaf, stem plus leaf sheath, and ear were not significantly influenced by phosphate level.

Yield and yield components (Table 2) were not significantly different among treatments throughout six-year experiment. Yield of reduced phosphate application treatments exceeded 650 kg/10 a even in 2003, which was the only year in six years whose summer temperature was lower than an average year and was, although the damage was slight in the experimental area, a cool-summer-damage year. In addition, contents of chemical components related to palatability and quality of brown rice appearance were investigated in 2005 and 2006, and no significant difference among treatments was found.

Above-mentioned results showed that growth, yield and quality of brown rice were not significantly affected even if phosphate application in Andosols paddy field was reduced by 25-50% compared to the present recommended level. Furthermore, reduced phosphate application did not significantly influence growth and yield even in the slight cool-summer-damage year. These results show that reduction of phosphate application by 25-50% is practicable without resulting in declined quantity and quality of rice production unless temperature condition is too severe. It is most likely that sustained growth and yield under reduced phosphate application was attributed to high phosphate availability of soil resulted from a repeated heavy phosphate application for many years before this study was started. It would be quite reasonable that reduced phosphate application did not give significant effect on palatability, because phosphate is not an element that has dominant effect on palatability.

High phosphate availability of soil was confirmed by the available phosphate content of the soil (30.5 mg/100 g) determined for the soil sample collected in April 2001, just before the start of this study. Soil diagnosis reference in Japan sets the reference value for available phosphate content for volcanic ash soil as 5.0 mg/100 g. The content of available phosphate in the soil before the start of this study was about six times as much as the reference value. High level of phosphate accumulation in Andosols[3] was confirmed.

To estimate annual phosphate balance in each treatment, the available phosphate content of the soil of each plot before and after the cropping season was plotted against time axis. As for Cont., -1P and -2P, data from 2001-2006 were used, and as for -3P, data from only 2005-2006 were used. The slope of the regression line of [available phosphate content of soil] - [time] plotting gives good estimate of annual balance of available phosphate content of the soil in each treatment. The response of annual balance of

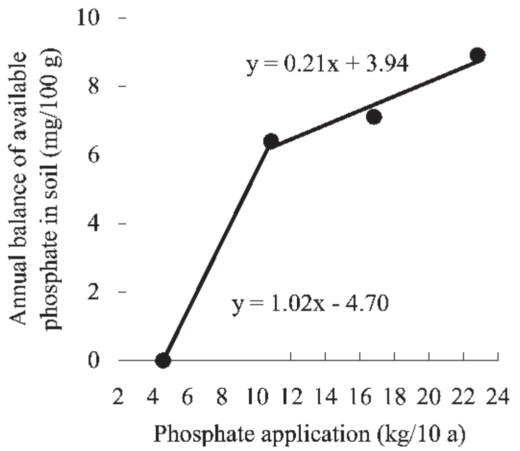

Fig.1. Annual balance of available phosphate in the soil in response to phosphate application.

available phosphate content of the soil to the phosphate application amount was analyzed. The analysis gave the estimation that annual balance reaches zero at phosphate application of 4.6 kg/10 a (Fig. 1), which is about 20% of present recommended application amount. When available phosphate content of the soil, 30.5 mg/100 g, is taken into account, and if the decline of phosphate content of the soil is allowed until it reaches 15 mg/100 g, half the amount of present, phosphate application of 4.0 kg/10 a (corresponds to -3P treatment in 2005 and 2006) can be continued for about 25 years by simple arithmetic.

The amount of phosphate uptake during a cropping season by rice plant was estimated to be 6.0 kg/10 a at most, based on the phosphate contents and dry weights of rice plant samples collected at harvesting stage. The loss of phosphate by surface water runoff was estimated to be 0.6 kg/10 a and the amount of natural supply of phosphate by irrigation water to be 1.4 kg/10 a. Since rice plant except harvested organs, hulls and brown rice, was returned to the paddy field after harvest every year, the amount of phosphate returned to paddy field was also estimated. Because the content of phosphate in hulls and brown rice was not determined in this study, the difference (2.6 kg/10 a) between the amount of phosphate in whole plant (6.0 kg/10 a) and that in ear (3.4 kg/10 a in average over treatments) was regarded as the amount of returned phosphate. Summarizing these results, the estimated annual input and loss of phosphate at zero-balance (equilibrium) were 8.6 kg/10 a and 6.6 kg/10 a, respectively. The difference between the two values would be partly explained by the change of inputted phosphate from available to unavailable form, since the annual balance of phosphate was based on the amount of available phosphate.

Recent study reports that proper phosphate application amount in paddy fields in Japan is equal to the amount of phosphate removal by harvested organs, hulls and brown rice.[4] Phosphate application rate estimated to give equilibrium of phosphate balance, 4.6kg/10a, in this study seems fairly good estimate. Reduction of phosphate application by at least 25%, monitoring of available phosphate level of soil and proper application of calcium that help phosphate accumulated in soil change into available form should be urgently established as a standard soil management practice.

Acknowledgements

The authors appreciate Dr. Seishi Yoshida of Chushin Agricultural Experiment Station, Nagano Prefecture, for providing facility for chemical analysis of plant and soil samples and for instruction on the analysis operation.

References

1) Ishizuka, Y., *Physiology of the Rice Plant*, Advances in Agronomy 23, 241-315, (1971).

2) Yoshida, S., *Fundamentals of Rice Crop Science*, IRRI, 1-269, (1981).

3) Mishima, S., S. Itahashi, R. Kimura and T. Inoue, *Trends of Fertilizer Demand and Phosphate Balance in Farmland Soil in Japan*, Soil Science and Plant Nutrition, 49, 39-45, (2003).

4) Ono, S., Ogawa, Y., Takahashi, S. and Ohno, S., *The Removal of Phosphorous and Pottassium by Rice from Paddy Fields and Appropriate Applying Amount of These Elements to Rice*, Japanese Journal of Soil Science and Plant Nutrition, 70, 320-323, (1999). in Japanese