Phosphorus conventional use, reduction potential, and possibility of self-sufficiency during food and feed production in Japan

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Abstract

Japanese agriculture uses huge amounts of phosphorus (P) for food and feed production. As a result, soil P fertility (soil test P, measured by the Truog method) has increased in the past 40 years. Because P is a limited, exhaustible resource, and agricultural P use should based on soil test P, effective use of P in agriculture is important. In this study, we estimated agricultural P flow and the possibility of chemical fertilizer reduction based on soil test P from one region's reduced input guidelines in 2000. Based on our estimation, chemical fertilizer application levels do not differ significantly over different soil test P levels. If chemical fertilizer application were cut based on soil test P, application could be reduced from 61.6 kg P ha^{-1} to 25.8 kg P ha^{-1} on average. Next, we estimated the non-utilized P resources in Japan. We focused on non-utilized livestock waste, food refuse, sewage sludge and iron slag as a promising P resource. The total P in these resources was estimated at 237 Gg P, comparable to conventional chemical fertilizer applications (276 Gg P), and enough self-sufficiency when chemical fertilizer application is reduced based on soil test P (115 Gg P). Reduction of the environmental impact (eutrophication potential) by reduced chemical fertilizer input would be from 973 to 776 in terms of index value and utilization of non-utilized P resource would be more worth for environmental issue.
Keywords: agriculture, phosphorus, reduced fertilization, self-sufficiency, impact to water in environment.

WIT Transactions on Ecology and The Environment, Vol 170,
www.witpress.com, ISSN 1743-3541 (on-line)
doi:10.2495/FENV130171

1 Introduction

Phosphorus (P) is one of the most important nutrient ingredients in plant fertilization. Because P is an endangered and exhaustible resource on the earth, and Japan import all its P from limited-resource countries, effective use of and sustainable management of P is important. However, agricultural use of as fertilizer is not efficient in Japan. For example, the soil-surface P balance, calculated by total P input to farmland through fertilizers etc. minus crop withdrawal, is highest in Japan among the Organization of Economic Co-operated Development (OECD) countries [1]. In other words, the amount of P input to farmland through fertilizers is much larger than crop withdrawal. As a result, huge amounts of fertilizer P are hoarded in the farmland soil, increasing the risk of polluting the water environment such as blooming toxic blue-green algae or red tide as the result of eutrophication [2]. In this study, we estimated amounts of chemical P from fertilizer and manure use, and in food and feed production, and classified it using a soil test for P (Truog-P). Then, we estimated the potential reduction in chemical P by fertilizer use according to the soil test P. Finally, we propose a possibility for mitigation by appropriate chemical P fertilizer use.

2 Materials and methods

2.1 Data sources

We used individual data from the questionnaire (4,433 inputs) named the 5th “Basic Soil Environment Monitoring Project, Stationary Monitoring” conducted between 1999 and 2003 by the Ministry of Agriculture, Forestry and Fisheries (MAFF), Japan as a application to obtain chemical P fertilizer and manure P, food and feed productivity classification by soil test P and area classification by soil test P. To implement the Japanese total planted area from the planted area obtained from the questionnaire classified by soil test P, MAFF’s statistics [3] were used. We focused on the year 2000. More than 70 food and feed items were summarized into 7 groups namely, paddy rice, upland crop, vegetable, orchard, tea, forage and fodder.

2.2 Guidelines for reduced chemical P fertilizer application

Hokkaido Fertilization Guide [4] showed the relations between soil test P and possible chemical fertilizer reduction in kinds of crops. For example, if farmland soil has more than 26.2mg $100g^{-1}$ of soil test (Truog method) P, we thought there is no need to apply chemical P fertilizer for vegetable, while the soil with 4.4 to 13.1 mg $100g^{-1}$ of soil test P needs conventional chemical fertilizer application. We applied the Guide for classification of soil test P status for kinds of crops (classification range and degree of reduction is different in kinds of crops) to all Japanese farmland soils and reduction from Japanese conventional chemical fertilizer application.

2.3 Non-utilized P resources in Japan

We focused on iron slag, sewage sludge, food refuse and non-utilized livestock waste as non-utilized P resources in Japan.

2.4 Evaluation of potential damage to water in the environment

The indicator of Mishima and Kohyama [2] was employed for evaluation of changes in potential damage to water environment, although we cannot indicate the absolute value of damage to water environment, because of data limitations. By this method, potential damage, basically eutrophication, to surface water (*Impact*) is thought to be caused by residual P ($P_{residual}$) caused by fertilization and soil test P ($P_{soiltest}$) caused by past fertilization bound to suspended solids in the surface runoff (*SS*) as follows:

$$Impact = SS \times \left(P_{residual} + \frac{P_{soiltest}}{2}\right) \quad (1)$$

Degree of mitigation by reduced chemical fertilizer application that relate to "$P_{residual}$" is evaluated relatively by the change of "*Impact*" value

3 Results

3.1 Classification of planted areas for 7 crop groups

The composition of the planted area for 7 crop groups comes from the statistical year book [3] as shown in Figure 1. This planted area was classified into 4 or 5 ranks by soil test P [4] as shown in Table 1. Then, the composition of the planted area in each crop group in each rank was calculated as shown in Figure 2 by integration of the planted area, the statistical yearbook [3] and the ratio of the area in each rank in each crop category according to the questionnaire.

Table 1: Classification by soil test P and P application rate.

Classification		Low	Optimal	Hi+1	Hi+2	Too High
Paddy rice	P fertility	<4.4	4.4-8.7		8.7-13.1	>13.1
	Application	100%	100%		0%	0%
Upland crop	P fertility	<4.4	4.4-13.1		13.1-26.2	>26.2
	Application	100%	100%		80%	50%
Vege-table	P fertility	<4.4	4.4-13.1	13.1-19.6	19.6-26.2	>26.2
	Application	100%	100%	50%	25%	0%
Orchard and Tea	P fertility	<8.7	8.7-13.1	13.1-19.6	19.6-26.2	>26.2
	Application	100%	100%	50%	25%	0%
Forage and Fodder	P fertility	<4.4	4.4-13.1		13.1-26.2	>26.2
	Application	100%	100%		80%	50%

Units of P fertility: mg P 100 g^{-1} dry soil.

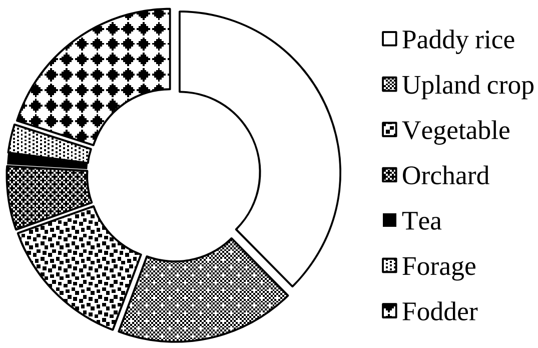

Figure 1: Composition of planted areas of crop groups. Total planted area was 4,475,000 ha in 2000 in Japan.

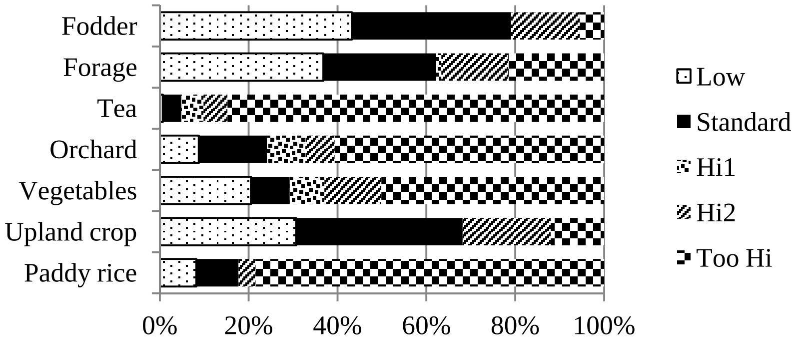

Figure 2: Classified planted area of crop groups by soil test P. More than half of the planted area of paddy rice, vegetable, orchard and tea was too high. Crop productivity, and chemical P fertilizer and manure application levels were not significantly different between different soil test P levels.

3.2 Chemical P fertilizer application, other P use and productivity

Chemical P fertilizer application in each rank of each crop group is shown in Figure 3. Because of large variances, chemical P fertilizer application in each soil test P rank was not significantly different among the crops by the Tukey test. From this result, chemical P fertilizer application was averaged for each crop without dividing soil test P rank. The chemical P fertilizer application rate for each crop is shown in Figure 4.

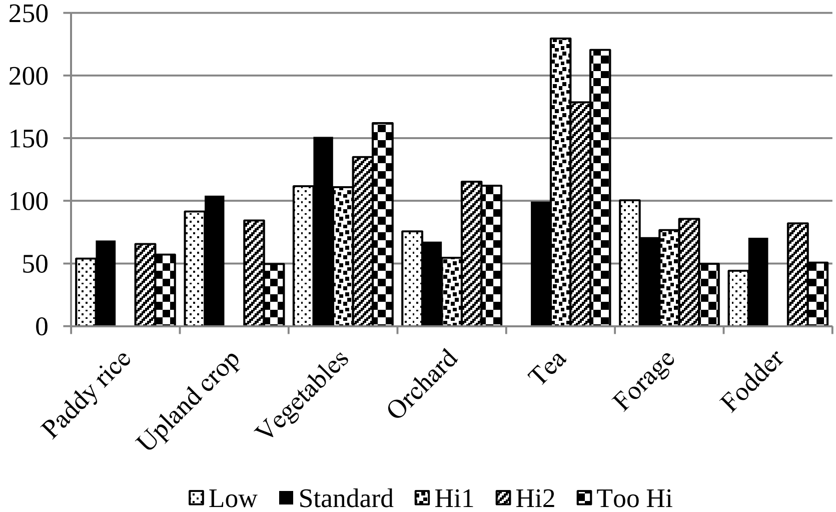

Figure 3: Chemical P fertilizer application for each level of soil test P for each crop group. In spite of differences in soil test P, chemical P fertilizer application was not significantly different between soil test P levels in each crop group.

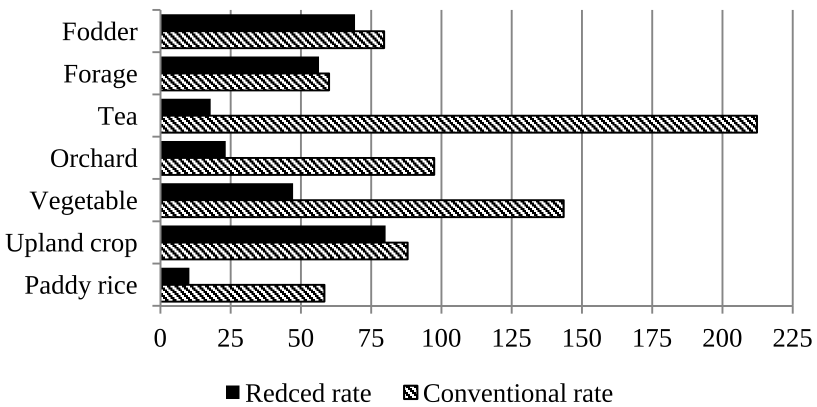

Figure 4: Conventional chemical P fertilizer application levels for each crop group, and reduced and optimized levels dependent on soil test P. A large reduction by optimization was observed in paddy rice, vegetable, orchard and tea because of the large values of soil test P. On the other hand, reduction was small for upland crop, forage and fodder because soil test P was predominantly optimal and/or lower than optimal in these crop groups.

Manure P and soil amendment P application was also not significantly different between the ranks of soil test P within crop groups due to large variances (data not shown). Crop P productivity was also not different by rank of soil test P within the crop groups (data not shown). The average of these data is shown in Table 2.

Table 2: Changes in relative water impact potential.

		2000		1990
		Conventional	Optimized	Conventional
Chemical fertilizer		61.6	25.8	54.8
Manure		15.0		18.9
Soil amendment		10.4		
Subtotal	(kg ha^{-1})	87.0	51.2	73.7
Crop yielding	(kg ha^{-1})	9.1		11.6
Balance	(kg ha^{-1})	77.8	42.1	62.1
Truog-P	(kg ha^{-1})	262		211
Area	(ha)	4,475,000		5,608,000
Indicator of Impact		935	776	940
Relative Impact (v.s. ’90)		100%	83%	100%

3.3 Reduction potential for chemical P fertilizer input.

Because more than half of the planted area for paddy rice, vegetable, orchard and tea is occupied by soil having “Too Hi” a soil test P, it was inferred that chemical P fertilizer application for these crops would not need to be applied in many cases, and that was a large reduced input potential for chemical P fertilizer. On the other hand, optimal or low values predominated on upland crop, forage and fodder, suggesting small reduction potential. The estimated average chemical P fertilizer input in the real situation, or under conventional and reduced conditions, is shown in Figure 4. Paddy rice, vegetable, orchard and tea would need less chemical P fertilizer than conventional and upland crop, forage and fodder for an optimal amount. In total, chemical P fertilizer application would be reduced from 61.6 kg P ha^{-1} to 25.8 kg P ha^{-1} by the optimization of application derived from soil test P (Table 2).

3.4 Estimated amount of P in non-utilized resources

Potentially available P in non-utilized resources is 98 Gg, 20 Gg, 26 Gg and 93 Gg in non-utilized livestock waste [5], sewage sludge [5], food refuse [5] and iron slag [6], respectively. The total P in non-utilized resources (237 Gg) is comparable to the chemical P fertilizer in conventional (276 Gg) or optimized (115 Gg) applications plus soil amendment (47 Gg).

3.5 Mitigation potential of potential damage to water in the environment

Mishima and Kohyama [2] estimated and tested the potential of damage to water in the environment by agricultural P in 1990. In 1990, agricultural P posed a risk of 940, the indicator value. In the same way, we calculated P surplus and amount from soil test P as given in Table 2. The risk value found was 935 for conventional and 776 for optimized use of chemical P fertilizer by the same indicator in 2000 (Table 2). The relative impact in 2000 versus 1990 was 100% and 83% for conventional and optimized cases, respectively.

4 Discussion

4.1 Chemical P fertilizer application and soil test P

In spite of low soil test P, crop P withdrawal in low soil test P was not significantly different from optimal or higher soil test P. Chemical P application was not significantly different among different soil test P levels. These results might indicate that chemical P fertilizer application had been carried out on low soil test P sites and no functional response from farmers was made after application. Such agricultural practice would be judged as resource-wasteful. We estimated chemical P application requirements dependent on soil test P, then determined that the chemical P fertilizer application levels would be reduced from 61.6 kg P ha^{-1} to 25.8 kg P ha^{-1}. Because this estimation is referenced in only 1 out of 47 prefectures, the methodology or degree of reduction is coarse and includes irrational arguments, even though the idea of reduction and optimization of application is sound. A finer and more precise scale of estimation would be needed for more realistic reduction and optimization of the margin of chemical P fertilizer application.

Some trials such as P equilibrium fertilization that supplies P by cattle manure that is equivalent to P withdrawal for fodder [7], and no P application during cropping when enough soil test P is observed [8] are practiced in Europe. However, P equilibrium fertilization reduces total soil P even though water-soluble P and ammonium-lactate extractable P is not affected, while no P application reduces crop yield.

Soil test P has increased on average, or on median, from the 1st survey to the 5th of the “Basic Soil Environment Monitoring Project, Stationary Monitoring” [9]. Although the degree of increase of soil test P might not simply be linked to the degree of higher P surplus, higher chemical P fertilizer application or higher manure application [10], we could say that P surplus conditions derived from any input of P would cause increasing soil test P values in the Japanese situation. Under these conditions, control of soil test P by adjusting P input by chemical fertilizer, manure or soil amendment would be difficult. Therefore, optimization of chemical P fertilizer might carry the risk of reducing soil test P. Soil test P should be linked to every P application. However, more information of P dynamics in farmland soils is needed. On the other hand, farmland soil over such a wide area has already been made too P rich. Therefore, reduction and optimization of chemical P fertilizer application is what is needed, precisely.

4.2 Amount of P in non-utilized resources

In Japan composting is thought to be the least popular method to reuse organic wastes, such as food refuse, sewage sludge and livestock waste in Japan. However, organic waste is sometimes polluted by heavy metals (cadmium, zinc, copper, etc.) [11, 12]. Therefore, application of organic waste compost needs caution or sometimes prohibition to prevent soil pollution. Currently, P recovery plants are operating commercially in some local sewage treatment plants (e.g. Gifu City [13]). In these plants, sewage sludge is incinerated, then P is collected from incinerated ash by an alkali-acid extraction-fixation method. The final product contains sufficiently low heavy metal content, and can be used as conventional chemical P fertilizer. While P recovery from iron slag is still a developing methodology [14], is it hoped that iron slag will be an important P resource because of its large P budget.

Composted material contains organic matter with nitrogen and potassium, therefore compost is an important nutrient source for farmland soil. However farmland soils have the capacity to consume compost with uneven distribution of organic waste, especially that from livestock waste [15]. In this case, incineration followed by extraction of P would be useful method to reuse P and the product of this process would be helpful for wide areas of distribution where the concept of manure has failed.

4.3 Mitigation potential of negative environmental impact and P recycling

We focused on the negative environmental impact by agricultural P use and its budget in farmland soil as surface water eutrophication by surface run off. Reduced input of chemical P fertilizer would be a simple and easy method to reduce this risk, although we cannot judge whether a reduction of 17% of the index value is significant towards environmental impact or not.

However, when we consider other direct and indirect effects, reduced and optimized P fertilization has many aspects, especially combined with P recycled from non-utilized wastes, such as resource saving, improved soil environment, improving the surrounding farmland environment and developing recycling pathways of by-products of P.

First of all, reduced and optimized chemical P fertilizer combined with P recycling can stuff chemical P fertilizer plus soil amendment P in national scale. This has the benefits of resource security and extraction of valuables from waste, and reduction of soil surface P surplus. Even though P application is reduced, soil surface P balance indicates a surplus (Table 2). Therefore while such a practice might not reduce soil test P, it might increase soil health by optimization of soil test P, and might prevent soil-borne diseases [16]. Non-utilized livestock waste is thought to be disposed to the surrounding farmland [17], at least around the year 2000. Now, disposal of waste by livestock on the farm is inhibited by the current law [18], which states that livestock waste should be treated by a sewage system or by incineration, and then sent to landfill. These processes produce useful materials for P recovery.

5 Conclusion

Because there is not enough scientific and experiential evidence to control soil test P, management of appropriate chemical P fertilizer, manure and soil adjustment is difficult. Provision of sustainable food and feed production would require keeping within a certain range of total P and soil test P in farmland soil to produce enough food and feed, especially in the soil top layer. Currently, there are trials to use soil test P budget as for newly applied chemical fertilizer and manure and/or simply limiting supplemental application of these P sources. So far such trials have not gone well and, therefore, more trials are needed toward the above provision. In Japan, basically the only available data is from soil test P measured by the Truog method. Of course, while soil test P is an important information source or index of soil condition, we would need more information such as total P, or a stronger extraction method than the Truog method (e.g. the Brey method) to better understand the condition of farmland soil, and lead to sustainable soil productivity.

Acknowledgements

We thank the researchers in the local agricultural experimental stations for collecting, adjusting and editing the questionnaire. The questionnaire data was provided by the National Resource Inventory Centre in National Institute for Agro-Environmental Sciences. This research was done as part of the JST-RISTEX project “Resource logistics as a support tool of science, technology and innovation policy decision.”

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