Nutrient Use and Efficiency in East Asian Agriculture

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Abstract

To determine the available nitrogen (N), phosphorus (P) and potassium (K) resource budgets (application minus plant uptake), we obtained data on inorganic fertilizers and livestock manure from statistical yearbooks for Japan, the Republic of Korea and China. Uptake of N, P and K via crop production was also calculated using national nutrient content factors. From the budget and crop production data, we calculated the N, P and K surpluses and use efficiencies. Japan used too much P, Korea balanced its use of inorganic fertilizer but needed to improve manure use, and China had high nutrient inputs and outputs in crop yield. To improve nutrient use efficiency and decrease the surplus, we set some guidelines, such as N, P and K output by crop yield should be more than 60 percent, 40 percent and 75 percent of applied inorganic fertilizer plus manure, respectively, or the inorganic N fertilizer application level should be around half of the crop yield, with the effectiveness of organic P and K as 100 percent of inorganic P and K fertilizers. Based on this analysis, we found that Japan should apply inorganic P fertilizer primarily to compensate for soil P deficiency, Korea should develop forage crop production and build recycling pathways within the country, and China should reduce its excessive use of N to reduce the N content of crops.

Key words: East Asia, nitrogen, nutrient balance, nutrient use efficiency, phosphorus, potassium

1. Introduction

Phosphorus (P) is the second-most important element in crop production, after nitrogen (N). Sheldrick *et al.* (2002) identified a rapid increase in P deficiency around the world after 1987. This suggests that more P fertilizer, obtained mostly from rock phosphate, will be needed to sustain future crop production. Sustaining crop production, however, also requires appropriate amounts of other key nutrients, such as N and potassium (K). To develop more appropriate regimes for the use of N, P and K, the budgets for these nutrients (*i.e.*, the balances between application and uptake by crops) need to be determined.

Sheldrick *et al.* (2003) audited Chinese N, P and K consumption, and found that K deficiency was the limiting factor in Chinese crop production. They also believed that the Republic of Korea (hereafter, "Korea") provided a useful model for managing nutrient supply to crops. The Organization of Economic Cooperation and Development (OECD), however, suggested that Korea had the third-highest soil surface N balance (the total N input to farmland minus the total N output from farmland) among OECD countries (OECD, 2008). Thus, Korea might not be an appropriate model for N use by other Asian countries such as China. Japan has the largest P surplus in OECD countries (OECD, 2008). Sheldrick *et al.* (2002) also noted high use of P in Japan, in addition to high N and K application. This appears to be based on the perception that half of Japanese upland fields, which are dominated by andosols, have strong P fixation activity (*i.e.*, low P availability), and therefore require large inputs of P. Yoshiike (1983) reviewed soil P fertility in Japan and found that Japanese farmland lacks sufficient available soil P; 44 mg P kg^{-1} dry soil would be needed to provide enough P to sustain crop yields. Japan's Ministry of Agriculture, Forestry and Fisheries (MAFF, 2005) set this value as the lower limit for soil P availability in the Soil Fertility Enhancement Act implemented in 1984. On the other hand, Japan had the fourth-highest soil surface N balance among OECD countries (OECD, 2008). Sheldrick *et al.* (2002) noted that farmers in Japan use large amounts of N fertilizers to improve the yield of paddy rice. Mishima (2001a), however, reported a trend towards reduced application of inorganic N fertilizer in the cultivation of paddy rice.

These sometimes conflicting conclusions resulted from different assessment perspectives and objectives. All food produced by farmers ultimately derives from food crops (*i.e.*, vegetables and cereals) and feed crops (*i.e.*, livestock fodder). Therefore, sustainable crop production is essential for maintaining a nation's food supply. Determining appropriate fertilizer usage is the basis for sustainable crop production. To support this goal, we calculated the national available N, P and K fertilizer budgets and crop N, P and K uptake in 2010 for three representative countries: Japan, as an example of a country with high fertilizer application levels; Korea, as an example of a country that practices rational nutrient use (Sheldrick *et al*., 2003); and China, as an example of a country with a K deficit (Sheldrick *et al*. 2003). We then compared the results of the three countries to seek insights into better N, P and K use in East Asia.

2. Materials and Methods

2.1 Framework

Figure 1 shows the nutrient flow model that we used as the framework for our study. We set a goal of assigning all livestock waste to storage and composting. We set human waste in rural areas as a source of nutrients in China. During storage and composting of livestock waste in the three countries and human waste in China, part of the K and P is lost through leaching. Part of the N is lost through volatilization as ammonia, nitrous oxide or N_2 and through leaching. The remaining livestock wastes stabilize as manure with certain N, P and K concentrations that differ among the countries. Manure represents an important potential national source of N, P and K that can be recycled via crop production. National statistics on inorganic fertilizer demand and consumption were obtained from statistical yearbooks (see Section 2.2 for details) and used to represent the N, P and K supplies used for crop production. The sum of manure and inorganic N, P and K fertilizer represents the total potential inputs to farmland soils to support crop production. The crop yield represents the output of N, P and K from the farmland. The balance for each element represents the budget (amount applied) minus the output in crops, and indicates a surplus or deficiency.

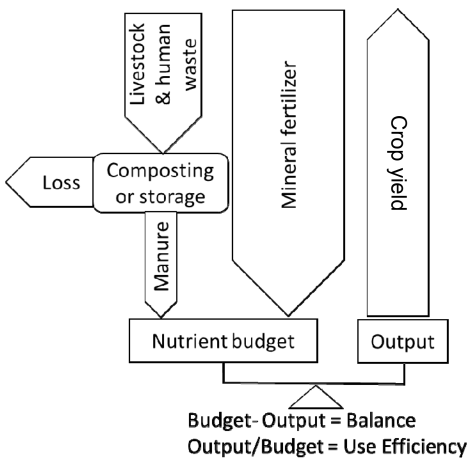

Fig. 1 Framework of this study.

To calculate the uptake and output values, we used conversion factors specific to each country that translated the statistical data for inputs and outputs into amounts of N, P and K.

2.2 Calculations

In Japan, livestock waste N, P and K production per head of livestock was obtained from feed consumption data (MAFF, 2011a), multiplied by the concentrations of N, P and K in the feed (Japan Livestock Industry Association: JLIA 2010). Consumption of feed by different kinds of livestock (MAFF, 2011b) was used in the calculation developed by Tsuiki and Harada (1997) for N and P and the equation by Ikumo (2001) for K to get livestock waste production. For Korea, data on livestock waste production per capita were obtained from Yun *et al.* (2013). For China, data on livestock and human waste production per capita were obtained from CAAS (Chinese Academy of Agricultural Science, 1994). Here, half of the Chinese population was considered rural (Mou, 2011), who would use their waste as manure. The loss of P from manure during composting was based on data from Matsumoto *et al.* (2006). Losses of N and K were calculated as the difference between the N:P and K:P ratios in livestock wastes and the corresponding ratios in the composted manure (Mishima *et al.* 2008). National manure N, P and K concentrations were obtained from Furuya (2005) for Japan, Um and Lee (2001) for Korea, and CAAS (1994) for China.

Inorganic fertilizer demand and consumption for Japan and Korea were obtained from the Pocket Fertilizer Handbook (Norin Tokei Kyokai, 2012) and from MFAFF (Ministry of Food Agricultre, Forestry and Fisheries, 2012), respectively. The China Agricultural Yearbook (Ministry of Agriculture (MoA), 2011) provided the national consumption of single-ingredient N, P and K fertilizers and of compound inorganic fertilizers. Because N, P and K ratios in typical compound inorganic fertilizers are not provided, we estimated these ratios by dividing the amount of compound inorganic fertilizer by the N:P:K ratios in single fertilizers. We used the sum of the single and compound inorganic fertilizers to represent the Chinese national total.

The total inputs of N, P and K to farmland equaled the sum of the manure and inorganic fertilizer inputs.

Crop yield data were obtained from the Statistical Yearbooks of Japan (MAFF, 2011a), Korea (MFAFF, 2012) and China (MoA, 2011). The N, P and K contents of agricultural crops were obtained from each country's native values: the Food Composition Table 5th edition for Japan (Ministry of Education, Culture, Sports, Science and Technology (MECSST), 2001), the Feed Composition Standard for Japan (JLIA, 2010), the Food Composition Table 8th edition for Korea (Rural Development Agency, 2011) and the China Fertilizer (CAAS, 1994). The yield of each crop was multiplied by the corresponding N, P and K concentrations to determine the N, P and K outputs from farmland.

Inputs of N, P and K minus the corresponding outputs in crops equaled the corresponding surplus (a positive value) or deficiency (a negative value). We calculated the nutrient-use efficiency by dividing the outputs of crops by the corresponding inputs. We defined the inorganic fertilizer efficiency or manure efficiency as the outputs divided by the corresponding inputs.

To allow a comparison among the three countries, all input, output and balance values were expressed per unit cultivated area (per ha). Data on the cultivated areas were obtained from MAFF (2011a) for Japan, MFAFF (2012) for Korea, and MoA (2011) for China. Note that because cultivation of multiple crops per year was possible in some regions, we counted some areas two or three times to estimate the total cultivated area. This is justifiable because a new fertilizer application is performed for each new crop.

3. Results and Discussion

3.1 Crop production and nutrient contents

China had the largest cultivated area because of the country's large size and the need to support a huge population (Table 1). The area of food and feed crops was smaller than the total cultivated area in Japan and Korea, but was 1.7 times the cultivated area in China (Table 1). This is because many Chinese farmers and some Japanese and Korean farmers cultivate multiple crops per year, especially in the southern coastal regions (MoA, 2011). More than half of the cultivated area was occupied by paddy rice in Korea. The smallest proportion of paddy fields, amounting to about one-quarter of the cultivated area, was in China (Table 1), but paddy rice accounted for the largest area of any crop in China and Japan (MoA, 2011; MAFF, 2011a).

Although the crop composition differed among the countries, the cultivated area in China was 27 times that in Japan and the area of food and feed crops (after accounting for multiple crops per year) was 48 times that in Japan. Korea produced 25% of Japan's fresh weight of crops from 35% of Japan's farmland area, despite producing 32% less paddy rice than in Japan (Table 1). Higher productivity in Japan was supported by fodder production to sustain dairy and beef cattle (MAFF, 2011a). The area of fodder production in Japan was relatively large (759,100ha = 18% of the total crop area by MAFF 2011a). The other typical crop was fiber crops in China, which accounted for a much higher proportion of the cultivated area than in Japan.

Crop N, P and K contents were considerably higher in China than in Japan or Korea, particularly for paddy rice (Table 1). As a result, N, P and K outputs in crops were highest in China, at 48, 74 and 50 times the respective corresponding Japanese values (Table 1). Outputs of N, P and K in Korea amounted to 21, 28, and 11%, respectively, of the corresponding Japanese outputs. The low P and K outputs in Korea were caused by different production structures; Japan has a large area of forage (118,417ha) and fodder fields (these occupied 21% of the cultivated area), and these crops have high N and K concentrations (JLIA, 2010).

3.2 Nutrient budget in human and livestock wastes

Japan had a larger dairy cattle population than Korea and China (Table 2). Korea had about the same population of beef cattle and swine as Japan, even though the area cultivated in Korea was only 37% of the corresponding area in Japan. Korea has no area of land used to grow feed for dairy and beef cattle. This situation would make recycling of livestock waste in farmland difficult, like the practice of recycling manure in intensive dairy and beef cattle areas in Japan (Mishima 2001b). China had 28, 47 and 19 times the numbers of dairy + beef cattle, swine and poultry, respectively, as Japan, with 27 times the cultivated area of Japan. There were large differences in the waste N, P and K production per head of each kind of livestock and in the N, P and K contents and ratios of the manure in composted and fresh material (Table 2). These differences would reflect differences in the nutrient content of the feed, in the composition of the feed, and in the composting practices in each country. Even in Japan, the basic units of livestock waste production as amounts of N, P and K (*e.g.*, Kohyama *et al.*, 2006;

Table 1 Crop production and nutrient content.

	Area (ha)			Production (Mg)			Nutrient content (% Fresh weight)			Nutrient Production (Mg)		
	Japan	Korea	China	Japan	Korea	China	Japan	Korea	China	Japan	Korea	China
Cultivated area	4,593,000	1,715,301	121,715,900									
Food and feed crops	4,244,000	1,474,654	201,935,300	65,099,023	16,582,442	1,766,644,577	N: 0.03–5.65 P: 0.00–0.92 K: 0.00–0.30	N: 0.03–5.79 P: 0.00–0.62 K: 0.00–0.26	N: 0.00–8.96 P: 0.00–1.42 K: 0.00–8.18	N: 432,542 P: 48,769 K: 328,223	N: 92,721 P: 14,097 K: 39,365	N: 20,923,602 P: 3,625,053 K: 16,588,133
(Paddy rice)	1,625,000	892,074	29,873,400	8,478,000	5,810,817	195,761,000	N: 1.09 P: 0.29 K: 0.23	N:1.04 P:0.15 K:0.15	N: 2.48 P: 0.48 K: 3.09	N: 92,410 P: 24,586 K: 19,499	N: 60,432 P: 8,716 K: 8,716	N: 4,854,873 P: 939,653 K: 6,049,015
Fiber crops	899	–	5,111,600	11,500	–	6,592,702	N: 0.39 P: 0.03 K: 0.23		N: 0.57 P: 0.13 K: 0.10	N: 45 P: 3 K: 26	–	N: 37,578 P: 1,978 K: 6,593

Table 2 Livestock holdings and waste production per head in 2010.

	Livestock holding (head)			Waste production (g $head^{-1}$ day^{-1})									Manure nutrient content (% Dry weight, *: % Fresh weight)								
				N			P			K			N			P			K		
	Japan	Korea	China	Japan	Korea	China	Japan	Korea	China	Japan	Korea	China	Japan	Korea	China*	Japan	Korea	China*	Japan	Korea	China*
Dairy cattle	1,484,000	429,547	14,201,000	229.0	174.5	104.4	39.3	53.9	14.0	81.4	40.5	130.1	2.10	2.06	0.50	0.90	1.22	0.13	1.83	0.45	0.71
Beef cattle	2,892,000	2,921,844	106,264,000	215.1	78.8	104.4	45.5	22.7	14.0	134.3	125.6	130.1	2.10	2.06	0.50	0.90	1.22	0.13	1.83	0.45	0.71
Swine	9,768,000	9,880,632	464,600,000	24.9	22.4	33.1	6.5	2.9	12.9	6.7	6.9	20.3	2.86	2.68	0.38	1.88	3.05	0.16	1.86	0.77	0.32
Poultry	285,536,000	149,199,689	5,352,510,000	0.8	1.4	0.5	0.1	0.2	0.2	0.2	0.5	0.4	2.89	5.10	1.29	2.24	2.11	0.54	2.23	1.45	1.30
Human*			667,370,000			12.0			3.2			3.7			N.A			N.A			N.A
Sheep and goat			280,879,000			15.6			2.8			10.0			0.78			0.15			0.74

Ikumo, 2001) and nutrient content in manure differed (MAFF, 1982; Furuya, 2005).

Table 3 summarizes the total livestock waste production and the calculated composted manure N, P and K amounts for each type of livestock, based on the N:P and N:K ratios for each country (Furuya, 2005; China Agricultural Technology Extension Center (CATEC), 1999; Um & Lee, 2001) and the rate of P loss based on an assumed 7% loss rate (Matsumoto *et al*., 2006). The largest proportional N and K losses were observed in Korea, and the smallest were observed in China. The Japanese proportional losses of N and K were close to those in Korea. Proportional losses of P did not differ among the countries because they were based on a single assumed rate; future research should determine whether the rate differs among the three countries. Based on the available data, we could not include the effects of co-materials that are added to livestock wastes, such as wood chips, rice husks, and rice straw, that contain N, P and especially K (Um & Lee, 2001), during the composting process. Thus, these losses of N, P and K are likely to be inaccurate. The small losses of N and K in China, however, suggest that Chinese manure might not be fully composted. In Korea, composting is done by composting companies, so livestock waste is generally composted sufficiently to provide a consistent commercial product. In Japan, composting is done both by composting companies and by individual farms, especially since 2004, when the *Livestock Waste Management Act* came into full force. Under this act, the government intended for livestock farmers to produce mature and homogeneous manure with a high nutrient content from livestock wastes (Yamada *et al*., 2006). Producing mature compost is important, because the ammonia content and/or growth inhibitors such as phenol, lower fatty acid, tannin, etc. in immature compost have been shown potentially to damage to crop roots (Sato, 2006), although the low K loss in China might mitigate the national K deficiency indicated by Sheldrick *et al*. (2003). Several trials using mature compost with high and balanced nutrient contents by blending have been conducted in Japan (*e.g*., Matsumori *et al*., 2005). In one example, the N, P and K content in cattle waste compost blended with rape seed residue was found to be 3.5%, 3.2% and 3.1%, respectively, the dry matter of which had an N: P: K ratio of 2.5: 1: 1.8. In cattle and poultry waste manure, the figures were 3.4%, 2.8%, 3.2% (= 2 :1 :1.6; Matsumori *et al*., 2005). The N: P: K ratio in livestock manure is usually 1.2–1.7: 1: 0.9–1.5 (from Table 2), therefore, blended compost has more N and K than usual manure. The use of such technology would be helpful in improving the use of livestock wastes in these three countries.

Table 3 Livestock waste production and potential manure production.

		Japan	Korea	China
N	Waste	521,406	265,863	15,595,604
	Loss	324,833	177,750	3,533,718
	Manure	196,573	88,113	12,061,887
P	Waste	103,497	58,001	4,270,029
	Loss	7,245	4,060	298,902
	Manure	96,252	53,941	3,971,127
K	Waste	230,027	129,842	11,824,034
	Loss	67,672	50,202	1,549,720
	Manure	162,354	79,639	10,274,314

Unit: Mg

3.3 Inorganic fertilizer use

Table 4 summarizes the use of inorganic fertilizers in crop production. From these values, we calculated the N:P and N:K ratios. Compared with Korea and China, Japan had a low N:P ratio. This resulted from high P inputs rather than from low N inputs, because the acidic soils and large proportion of andosols in cultivated fields have led farmers to assume low P availability and the need for supplemental P fertilization (Yoshiike, 1983). The N:P ratios were similar in Korea and China. The K:P ratio, however, was highest in Korea and lowest in China. Low K input might be caused by high prices and low affordability of inorganic K fertilizers for Chinese farmers (MoA, 2011), because China does not produce K-containing ore and must import this resource.

3.4 Nutrient surplus or deficiency and nutrient use efficiencies

All the results were divided by the respective cultivated areas to facilitate comparisons among the three countries (Table 5). China had the highest potential manure budget, inorganic fertilizer use, and crop yield (output) of N, P and K. The balance between the potential N, P and K inputs in manure plus inorganic fertilizers and the crop yield (output) revealed a large surplus, even of K, in China.

China had the largest nitrogen surplus, with a value 7.5 times that of Japan and 2.7 times that of Korea. Japan had the smallest N surplus, which resulted both from the high N loss during composting and the low input of inorganic fertilizer in Japan and Korea. In China, the average N input to paddy rice was 113 kg N ha^{-1} (Jin, 2012), versus 59.5 kg N ha^{-1} in Japan (Norin Tokei Kyokai, 2012), although we do not have data for Korea. A large proportion of the N applied in China (34%, Jin, 2012; 23% Zhu & Zhang, 2010) is thought to be lost after application as ammonia or denitrification in alkali soils (Xu, 2006) and due to microbial activity. If we subtract

Table 4 Mineral fertilizer use.

	Japan		Korea		China	
	Amount(Mg)	Ratio*	Amount(Mg)	Ratio*	Amount(Mg)	Ratio*
N	574,177	2.337093	211,217	6.827202	34,838,304	6.691574
P	245,680	1	30,938	1	5,206,294	1
K	463,078	1.884885	69,301	2.240022	7,233,002	1.38928

*: Against amount of P

this 34% or 23% of total N input budget (=170 or 115 kg N ha^{-1}), the N surplus is smaller, but the value (158 or 213 kg N ha^{-1}) is still higher than the corresponding values in Japan and Korea.

The inorganic fertilizer use efficiency in Japan was about twice the levels in Korea and China, which had similar efficiencies. About 50% of the N in crops in Japan is believed to come from inorganic fertilizer and the rest from manure and soil organic matter (Matsumoto & Kurihara, 1994). Therefore, the high inorganic fertilizer application rates in Korea and China might be needed to sustain high crop production. The high efficiency of inorganic fertilizer use in Japan is supported by the high N concentration (0.46% in fresh weight) and high productivity (36,332 kg fresh weight ha^{-1}) of fodder crops (MAFF, 2011a; JLIA, 2010). Mishima *et al*., (2013) have suggested a small N surplus in fodder fields as well as in paddy rice, but a deficiency if the manure input is excluded (Table 5).

Manure N efficiency was more than 100% in all three countries. The highest Japanese manure N efficiency resulted from a large N loss during composting (Table 5). Korean and Chinese manure N efficiencies were around 100%, namely, the manure N budget was as large as the crop N yield (Table 5). Manure N is expected to be soil organic N in the end. We should focus on the trend of soil N quantity and available N in the soil. Nutrient use efficiency in total was lower in Korea and China than in Japan. Although their inorganic fertilizer application may be reasonable, the higher potential manure N supply decreased the efficiency compared with Japan (Table 5). Sheldrick *et al*. (2002) stated that the N use efficiency in Korea and China was ca. 50%, which is close to the values found by the present study. If half of the N in the crop comes from inorganic fertilizer and the other half come from soil or manure N, each efficiency would be 100%. With this in mind, China and Korea should reduce mineral N fertilizer. To achieve sustainable crop production it will be necessary to find a better balance between the use of N from inorganic fertilizer and that from manure.

The P surplus was largest in China and lowest in Korea (Table 5). China had the largest P output in crop yield, at 2.7 times that of Japan and 3.8 times that of Korea. China, however, had the largest P content in inorganic fertilizer and manure, which gave China the largest P surplus. Traditionally, Korean soil fertility management has been based on the available soil P. Therefore, P is expected to be well managed, and soil P fertility is expected to be affected less by fertilizer inputs in Korea (Kim *et al*., 2011) than in Japan (Mishima *et al*., 2013). Inorganic fertilizer efficiency for P is highest in China, at twice the value in Japan (Table 5). Japanese P input through inorganic fertilizer is too high compared with the yield (output) in crops, particularly compared with the balances in Korea and China (Table 5). This likely results from the unique soil types in Japan, especially the prevalence of andosols, which lead to higher P requirements. However, the P availability in soils increased from the late 1970s to the early 2000s in Japan (Obara & Nakai, 2004) and on this basis, Japanese P fertilization strategies should be revised to base P inputs on the actual soil P availability. In other words, Japan should reduce P inputs in fertilizer where the soil P availability permits such a reduction. Although their estimation was done for 2000, Mishima *et al*. (2013) stated that Japan could decrease its P fertilization to less than half the conventional rate (from 61.6 to 25.8 kg P ha^{-1}).

Nutrient use efficiency for P was highest in China, at 31%; this was nearly double the levels in Japan and Korea. Sheldrick *et al.* (2002) reported a P use efficiency of 40% taking into account both inorganic fertilizer and manure. The inorganic fertilizer efficiency was higher than this level in Korea and China, but not in Japan. The additional P input in manure, however, decreased the P use efficiency below 40%, especially in Korea, where the manure P input was larger than the inorganic fertilizer P input (Table 5). Kusaba *et al*., (2009) stated that manure P can be considered equivalent to inorganic P fertilizer in farmland soils that have been fertilized sufficiently then matured. Therefore, Korea might be able to replace some inorganic fertilizer with manure. The high crop P yield (output) in China has resulted in relatively high nutrient use efficiency. China should also be able to reduce its inorganic fertilizer inputs. For more sustainable crop production, China, Korea and especially Japan should investigate the soil P fertility in their own farmland through soil testing and manage it rationally for sustainable crop production and P resource governance.

The K surplus was largest in Korea and smallest in Japan (Table 5). Korea's large K surplus was caused by the low crop K yield, and the small K surplus in Japan was caused by having the smallest amount of manure K

Table 5 Nutrient balances in East Asian countries.

	N			P			K		
	Japan	Korea	China	Japan	Korea	China	Japan	Korea	China
Livestock waste (1)	185	155	166	25	34	44	50	76	132
(Loss) (2)	(144)	(104)	(32)	(2)	(2)	(3)	(12)	(29)	(20)
Manure (3=1−2)	41	51	133	24	31	41	38	46	112
Mineral fertilizer (4)	97	123	367	40	18	55	61	40	76
Nutrient bugdet (5=3+4)	138	175	501	63	49	96	99	87	188
Crop yielding (6)	94	54	172	11	8	30	71	23	136
Balance (7=5−6)	44	120	328	53	41	66	27	64	52
Mineral fertilizer efficiency (8=6/4)	98%	44%	47%	27%	46%	54%	118%	57%	179%
Manure efficiency (9=6/3)	228%	105%	129%	45%	26%	72%	188%	49%	122%
Nutirent use efficiency (10=6/5)	68%	31%	34%	17%	17%	31%	72%	26%	72%

kg ha^{-1}

and an intermediate crop K yield (Table 5). Although K deficiency was thought to be a limiting factor for Chinese agriculture (Sheldrick *et al*., 2003), our estimates suggest a large K surplus in China (Table 5). The inorganic fertilizer efficiency in China and Japan were both more than 100%, which suggests that the K yield in crops was larger than the input of inorganic K fertilizer (Table 5). In Japan and China, manure K efficiency is also more than 100% (Table 5), therefore, application of manure K as well as inorganic K fertilizer would be required to maintain soil K fertility. The reasons for this might include perceptions that the soil already has enough K availability (*e.g*., Obara & Nakai, 2004), K is sufficiently supplied from manure (Mishima *et al*. 2013), the price of mineral K fertilizer has risen recently (Norin Tokei Kyokai, 2012), the effect of K fertilizer application is sometimes unclear, etc. The higher crop K yield than the inorganic fertilizer input in Japan resulted from high K concentrations and high K yields in Japanese fodder crops, and in China, it came from the high K concentrations in Chinese crops (Table 1). Sheldrick *et al.* (2002) suggested a K use efficiency of 75%. The nutrient use efficiency in Japan and China was near this level, although this efficiency was only achieved after accounting for the manure K budget. In Korea, the K use efficiency was much lower, so it might be appropriate to use less inorganic K fertilizer (Table 5), although it will be necessary to consider the manure K budget carefully in the context of national K use for crop production. Kusaba *et al.* (2009) also stated that manure K can be used at levels similar to those of inorganic K fertilizer. Replacement of some of the inorganic K fertilizer with manure K would be possible, promoting a native and important K resource in Korea.

3.5 Required governance of resources in East Asia

Firstly, we calculated nutrient budgets and crop nutrient yields, referencing national statistics (*e.g*., crop yields, livestock holdings, mineral fertilizer use) published in each country and the country's native conversion factors (basic unit of waste production, manure nutrient content, food nutrient content, and so on) where possible, because conversion factors differ considerably between countries. If we were unable to obtain sufficient statistical data about the country in question, we referred to the Food and Agriculture Organization (FAO), which has national statistical data. We had no ideas for other data sources for conversion factors, such as crop nutrient concentrations, especially in developing countries. The FAO publishes food nutrition tables and this information might be helpful in the case of developing countries.

Livestock waste manure represents an important part of a country's native nutrient resource pool, and its effective use as a fertilizer source in combination with inorganic fertilizer could decrease the negative environmental impacts of agriculture and increase the sustainability of crop production. The first step toward achieving these goals would be a better understanding of the nutrient flows and contents, which can be used to develop sustainable fertilizer resource management regimes. Guidelines that consider effective use of organic and inorganic fertilizers would be based on nutrient efficiencies of N, P and K of 60%, 40% and 75%, respectively, according to Scheldrick (2002); livestock manure P and K effectiveness of 100% and 100%, respectively, of inorganic fertilizers, according to Kusaba *et al.* (2009); application of inorganic N fertilizer at around half of N in the crop output (Matsuzaka & Kurihara, 1994); and an N balance of less than 100 kg N ha^{-1} surplus, according to the OECD (2008).

Inorganic fertilizer use in Korea is around twice the N, P and K output in crops (Table 5). This may represent a reasonable and sustainable approach to crop production, but there is room for improvement in the use of manure N, P and K. To improve the sustainability of Korean crop production, agricultural managers should incorporate the production of forage crops such as dent-corn, sorghum and green rye, which have a higher feed yield per unit area than fodder yield (*e.g*., MAFF, 2011a), and should develop and enhance nutrient recycling pathways. Although there are regional problems in Japan (Mishima, 2001b), namely, Kagoshima and Miyazaki prefectures have no way to make complete use of livestock manure nor any method or technology to mitigate high N surpluses, the Japanese approach to animal husbandry, namely local land use for dairy and beef cattle, would be helpful in Korea.

In Japan, much more attention must be paid to P management based on the actual soil P availability of farmland, leading to the application of more appropriate amounts of P. The traditional Korean approach based on soil P availability would provide helpful guidance for managing soil P availability in Japan. N and K management might be appropriate in Japan, as the average N (60%) and K (75%) efficiencies followed those proposed by Sheldrick *et al*. (2002). Management of the available K budget of soil in Japan is not a priority, however, so K levels and the available P budget fluctuate widely (Mishima *et al*., 2013). High N and K contents in fodder in comparison with the values in the 1979 Feed Composition Table (MAFF, 1980) suggest a possible risk of methemoglobinemia or grass tetany in cattle. Japan must therefore improve its monitoring of fodder crop quality. Substitution of inorganic N, P and K fertilizer with manure N, P and K would improve sustainability of crop and livestock production in Japan.

China had a K surplus. Although the use of inorganic K fertilizer was insufficient, the potential manure K budget, which includes human feces from rural populations, appears able to compensate for any lack of K from inorganic fertilizer. Suitable distribution of livestock manure would increase the sustainability of Chinese crop production. Soil N and P availability in China has been stable or has sometimes increased, whereas soil K availability has been stable or decreased (Xu, 2006). Such decreases in K availability might be mitigated by increased use of livestock wastes or manure. Chinese manure, however, would be too immature under the current compost production system, because of the high concentration of N and K against P, and this might cause other soil-related problems (*e.g.*, too strongly reduced conditions in paddy rice fields) thus, more advanced composting technologies might be required.

4. Conclusions

Although P use efficiency was low in Japan and Korea, management of N and K appears to be acceptable and efficient in Japan. Inorganic N, P and K fertilizer management in Korea was reasonable compared with its management in Japan and China, although accounting for manure N, P and K reduces the nutrient use efficiency. This conclusion, however, depends on the assumption of a 7% P loss rate in livestock wastes and manure for all countries. Because composting technology is immature in China, this assumption should be tested in future research. Japanese P management is less rigorous than in Korea and China, though this results to some extent from the unique characteristics (low P availability) of Japanese soils; nonetheless, P management in Japan should be revised to better account for actual soil P availability. Achieving reasonable N and K surpluses and use efficiencies will depend strongly on fodder production in Japan. Chinese N, P and K resource budgets and outputs in crop production appear reasonable, but the high N surplus should be decreased through more efficient use of inorganic N fertilizers. The present results suggest that increasing soil availability and improving the use of livestock manure will be the key to sustainability in all three countries.

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