Recycling rate of N, P and K in animal feed and bedding material and use efficiency of manure N, P and K in agro-ecosystems

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Abstract
The losses of N and P in farmlands are of major concern due to their effects on economic and environmental sustainability in agro-ecosystems. We conducted a 9-year study to assess the cycling of N, P and K in farm produces and the use efficiency of manure N, P and K. It was found that the feeding-composting cycle caused an average loss of N, P and K in the harvested produces by about 55%, 15% and 10%, respectively. Under high-yielding conditions, the amounts of recycled N, P and K from the harvested produce and the feeding-composting cycle were about 30-50 kg N/ha, 8-14 kg P/ha and 18-30 kg K/ha, respectively, equivalent to 25-33% N, 36-65% P and 30-50% K fertilizers applied to the farming systems. The use efficiency of N, P and K in organic manures in the current season increased with the extended fertilization, indicating a contributing factor of soil residual effects. The use efficiencies of N, P and K in organic manures over the 9-year period were 58%, 38% and 44%, respectively. The results suggest that nutrient recycling in farming systems improves soil fertility and nutrient use efficiency, and also reduces the use of fertilizer.

Key Words
Feeding-composting system, recycling rate, use efficiency.

Introduction
Long-term fertilizer experiments worldwide have proved that balanced fertilization using fertilizers with organic manures can improve the nutrient status of the soil and maintain high crop yields and increase the SOC concentration. Many studies have demonstrated the effect of long-term manure applications on the chemical, physical and biological properties of soils. Such influences may be either direct or indirect. In general, the effects have focused on one or two aspects, such as Soil organic matter dynamics, N transformations, C mineralization and immobilization and the Nutrient cycling (Biederbeck *et al.* 1996; Velthof *et al.* 1997). Organic manure has been used as the main nutrient source for crop production in China for some thousands of years. However, in last two decades, there has been a large increase in the use of fertilizer with a concomitant decrease in the use of manure. These situations have contributed to many environmental questions. Recently, there is a revival of recycling organic manure, but now combined with fertilizer. Many studies have examined the influences of combined applications of animal manure and fertilizers (Fan *et al.* 2005). However, available information is still absent and incomplete about the nutrients recycling rates through feeding-composting cycle.

The consumption of farm produces by human-being and livestock, and the return of their excrements to the farmlands constitute a component of nutrient recycling in the agro-ecosystems. However, the amounts of recycled nutrients via a feeding-composting cycle are only a part of total nutrients in harvested produces. The course in which animals absorb N, P and K contained in fodders is affected by many factors, such as the animal species, age, raising conditions and fodder composition (Foth 1978). The loss of nutrients in excrements depends upon the ways of storage and composting. This study aimed at estimating the recycling rate of nutrient in harvested produces through a feeding-composting cycle and the use efficiency of nutrient in organic manure in northeastern China.

Materials and methods
Experimental site, design, and treatments
A long-term field experiment has been conducted since 1990 at the experimental station of the Institute of Applied Ecology, Chinese Academy of Science (Latitude 41°32'N, Longitude 123°23'E). It has an average elevation of 31m and a mean annual temperature of 7.5℃. Its annual precipitation is about 700 mm. The soil of the experimental field is an Alfisol, which is the main soil type used for agricultural production. The initial properties of the surface soil (depth 0-20 cm) were as follows: soil texture, clay loam; pH, 6.5; soil organic matter, 20.9 g/kg; total N, 1.13 g/kg; total P, 0.44 g/kg; total K, 16.4 g/kg; available P, 10.6 mg/kg; and

available K, 88.0 mg/kg.The experiment had eight treatments: no fertilizer (CK), recycled manure (M), N, NM, NP, NPM, NPK and NPKM treatments. Only four treatments with manure were involved in this paper. N, P and K fertilizer were applied at the rates of 150, 25 and 60, kg/ha/year in the form of urea, double superphosphate, and potassium chloride, respectively. All P and K fertilizers were basal-applied prior to sowing; 40 kg/ha N fertilizer was basal-applied before sowing, and 110 kg/ha N was top-dressed at the stem-elongation stage. Each plot area was 162m^2, with a buffer zone of 2.0m. Initially, in 1990, the experiment was started with a soybean-maize-maize rotation. Each treatment consisted of three replications. Through feeding-composting cycles, 80% harvested seeds, 100% soybean straw, and 50% corn stalk were returned to the original treatment. This completed a nutrient-recycling process that consisted of "fertilization-crop yield-absorption-feeding-composting-return to fields." All the feeding stuffs and bedding materials are just come from the harvested crop material. There are much different for the amount of manure among the treatments because the yields of crop were different. Although the feeding-compost trial was started from the fall of 1990, all the data in this paper is from 1999 to 2008.

Sampling and chemical analysis
Pig manure samples were taken before fertilization in the next spring and divided into two sub-samples. One was for the water content measurement and another was dried and ground for analysis of N、P and K. All the crop samples were taken after harvest and divided into two sub-samples. One sub-sample for the water content and another was dried at 70℃ for 24 hours and ground for analysis of N、P and K. A Vario EL Ш elemental analyzer was used to determine total N for soil, manure and crop samples. Crop P was made by colorimetry after digestion (Olsen and Sommers 1982). Crop K was made by flame photometer after digestion. Soil P and manure P was measured by colorimetry after high-temperature ignition in muffle furnace with Na_2CO_3 fussion at 920℃ (Jackson 1958). Soil available P was also measured by colorimetry after extraction with 0.5 mol/L $NaHCO_3$ (pH=8.5) (Olsen *et al.* 1954). Soil K and manure K was determined by flame photometer after NaOH fusion in a muffle furnace at 720℃ (Jackson 1958). Soil available K was determined by flame photometer after extraction with 1.0 mol/L NH_4OAc (Carson 1980).

Results and discussion

Nutrients recycle of feed stuffs and bedding materials
The residual rate of organic matter in the feeding stuffs and bedding materials through a feeding-composting cycle was about 0.22 (Table 1), slightly lower than the residual rate of organic matter applied to the soils for one year. This was mainly because the feeding stuffs had no longer mixed with soil since 1999 and the residual rate was decreased due to the absence of soil absorption. When the feeding stuffs were mixed with soil, similar residual rates were observed between the feeding-composting cycle and the application in soil.

Table 1. Mean residual rates of organic matter in feeding stuffs and bedding materials through a feeding-composting cycle during 1999-2008.

Treatments	Pig manure				Pig manure +N				Pig manure +N+P				Pig manure +N+P+K			
Parameter	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
Mean	239.7	59.72	0.24	0.76	330.0	75.5	0.21	0.79	350.2	79.88	0.22	0.78	367.4	82.49	0.22	0.78

A: dry wt. of stuffs and materials (kg); B: dry wt. of pig manure (kg); C: residual rate; D:decomposition rate.

The loss rates of N, P and K contained in harvested materials though the feeding-composting cycle were in average 55%, 16% and 10 % respectively, over the 9-year study (Table 2). The higher loss rate of N was due to the easy vaporization of ammonia, whereas the loss of P is mainly due to the digestion by pig. This experiment did not separate the loss of nutrients by pig digestion from that by composting. If a base estimation that animals absorb 20% of N and 10% of P is used (Foth 1978), the loss of P through composting is insignificant, but the loss of N is much higher. The loss of K through the feeding-composting cycle is negligible. Moreover, the study showed that the recycling rate of N differed slightly in different fertilizer practices. With the increase in fertilizer use, the recycling rate of N decreased from 52% to 42%, but the recycling rate of P and K was similar (86-82%; 92-87%, respectively).

Use efficiency of N, P and K in pig manure
Manures are an important source of nutrient supply in farming systems, especially in northeastern China. Using the amount of nutrients in the pig manure and the amount of nutrients in harvested materials of the recycling treatments year by year, we calculated the use efficiency of N, P and K in pig manure (Table 3). The average amount of N in the pig manure recycled farmland was 38-50 kg/ha, equivalent to 25-33% of N

Table 2. Mean loss rates of nutrients contained in feeding stuffs and bedding materials through a feeding-composting cycle during 1999-2008.

Treatment	Nutrients in stuffs and materials(kg)			Nutrients in pig manure(kg)			Recycling rate of nutrients			Loss rate of nutrients		
	N	P	K	N	P	K	N	P	K	N	P	K
Manure	3.47	0.49	0.98	1.83	0.42	0.90	0.52	0.86	0.92	0.48	0.14	0.08
Manure+N	5.08	0.57	1.23	2.21	0.47	1.09	0.41	0.83	0.89	0.59	0.17	0.11
Manure +N+P	5.38	0.73	1.28	2.34	0.61	1.22	0.44	0.84	0.92	0.56	0.16	0.08
Manure +N+P+K	5.89	0.82	1.65	2.42	0.67	1.44	0.42	0.82	0.87	0.58	0.18	0.13

fertilizer (150 kg N/ha) and was an important nutrient source for crop production. Although N use efficiency of the organic fertilizers varied between years, there was limited residual effect of organic fertilizer. In addition, N use efficiencies of the pig manure in the current season increased with the extended fertilization, indicating an existence of residual effects. Continuously applying organic fertilizers not only increases soil N-supplying capacity and N use efficiencies in the current season and adaptability to variation of rainfall in rain-fed agriculture area, but also reduces the dosage of mineral fertilizer use. This study showed that the pig manures provided an average amount of 9-14 kg P/ha and 18-30 kg K/ha to the recycled farmland, which was equivalent to 36-65% of P and 30-50% of K from fertilizers. With the increase of fertilizer use, the recycling rate of P and K decreased in terms of the requite lapse rate. Moreover, the study showed that P and K use efficiencies of pig manure in the current season increased with the extended fertilization, indicating a strong existence of residual effects (Foth 1978). The P and K use efficiency of organic manure were slightly higher than that of fertilizer P and K that was because the organic matter in pig manure had decreased P fixation by soil.

Table 3. Mean nutrients use efficiency of pig manure during 1999-2008.

Treatments	Pig manure			Pig manure +N			Pig manure +N+P			Pig manure +N+P+K		
Parameter	A	B	C	A	B	C	A	B	C	A	B	C
N	37.76	26.64	0.72	45.48	32.45	0.71	48.22	25.10	0.52	49.76	18.14	0.36
P	8.63	4.54	0.55	9.70	4.62	0.48	12.48	3.96	0.32	13.69	2.79	0.20
K	18.43	9.58	0.52	22.51	11.55	0.52	25.07	8.22	0.33	29.55	11.61	0.40

A: Nutrients in pig manure applied (kg/ha); B: Nutrients harvested (kg/ha); C: Nutrients use efficiency of pig manure.

Conclusion

The use of nutrients recycled in farming system improves soil fertility and nutrient use efficiency, and therefore reduces the use of mineral fertilizers. Under high-yielding conditions (150 kg N/ha, 25 kg P/ha and 60 kg K/ha), the average amounts of recycled N, P and K from 80% of harvested materials and through a feeding-composting cycle were 38-50 kg N/ha, 9-14 kg P/ha and 18-30 kg K/ha, equivalent to 25-33% of N, 36-65% of P and 30-50% of K from fertilizers applied every year. Over the 9-year period of study, the loss rates of N, P and K in harvested materials though a feeding-composting cycle were about 55%, 16% and 10%, respectively. Through composting, the loss of P and K was insignificant, but the loss of N was much higher, indicating P and K recycling was more efficient. N, P and K use efficiencies of the pig manure in the current season increased with extended fertilization, probably due to residual effects of pig manure. The averages of N, P and K use efficiency of pig manure were 58%, 38% and 44%, respectively. The increased P and K use efficiency of pig manure compared with fertilizer P was because the organic matter in pig manure had decreased P fixation by soil.

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