Research article

Estimating Nutrient Flux of an Integrated Agriculture-Aquaculture System in Peri-Urban Thailand

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Abstract There has been little information available on nutrient and heavy metal contents of animal manure (cattle, poultry and pigs) in Integrated Agriculture-Aquaculture (IAA) farm systems in Thailand and Southeast Asia. Such systems have an important role in these areas. In this study the nutrient and heavy metal contents were measured so that metal budgets could be constructed and "typical" rates of the inputs to IAA-farming systems calculated. This study was carried out over a period of one year (2007- 2008) in a peri-urban area in Thailand. Small scale pig farms in the peri-urban Pathum Thani province near Bangkok were considered typical of up to a third of total pig farms of the country. The specific objective of this study was to quantify nutrient and heavy metal (nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), copper (Cu) and zinc (Zn)) fluxes in (i) the agricultural systems with small scale pig farms and (ii) the downstream aquacultural systems with piggery waste-fed fish ponds. We quantified the amount of nutrients released as a result of farming and estimated the assimilative capacity of the surrounding environment. Nutrient inputs (feed) and releases as pig manure were sampled monthly in the fattening period (about 6-7 months) to provide information on the environmental load in that period. Information about nutrient and heavy metal fluxes in the IAA system can be used for farm management decisions with a view to decreasing the environmental impact of piggeries and fish farms. Nutrient and heavy metal flux data can be used as a basis for developing a practical tool to estimate nutrient flux for an IAA system.

Keywords IAA farming systems, peri-urban area, piggery waste, heavy metal

INTRODUCTION

As in other countries, Thailand experiences environmental impacts from livestock wastes. The major concerns are pollution of the air, soil and water, including surface water and groundwater. A growing population, increasing incomes, and urbanization are leading to rapidly-increasing demand for livestock products as well as significant changes in the size and structure of livestock industries. A large part of the increased supply is from larger-scale and land-detached production of pigs and poultry near urban centers. The result is a high concentration of N and P compounds in peri-urban areas, often leading to significant water and air pollution (Menzi and Kessler, 1998). With respect to animal wastes, piggeries are the most troublesome. Piggery waste has elevated concentrations of organics and N, and its level and composition per unit of time varies widely. These concentrations depend on factors such as the weight and age of pig, types of feed and water intake, feeding operations, management practices and climate (Choi, 2008). A practical waste management is to re-use animal manure as a source of nutrients and organic matter. However, there are components in pig slurry that are potentially dangerous for the environment (Dourmad and Jondreville, 2007). The manures contain heavy metals and trace elements, such as Zn and Cu, in high concentrations which accumulated in sludge.

Within the last decade, large-scale or industrialized pig farming has rapidly increased, especially in eastern and central regions of Thailand. Pig production is concentrated in the central provinces around Bangkok, an area which accounted for 36-40% of total pig production in the 1990s (Subasinghe, 2006). Intensive livestock rearing in peri-urban areas has resulted in enormous waste disposal problems with associated environmental impacts (Jesdapipat, 1998). Many studies have found that small and medium-sized farms cause more environment impact than large farms because the latter are industrial scale and have the capacity to manage waste according to regulations.

Cu and Zn are involved in many metabolic functions, and their provision in sufficient amounts in pig feed is necessary to ensure good performance and animal health (Nicholson et al., 1999). Consequently, these elements are commonly-occurring micronutrients and highly concentrated in pig manure which accumulates in soils where pig slurries are applied (Moral et al, 2008). A number of studies have measured Zn and Cu concentrations in pig feed and manures. Zn concentrations in piglet, fattening pig and sow feed were 212–2350, 173-986 and 158-198 mg/kg dry matter (DM) respectively. Cu concentrations in piglet, fattening pig and sow feed were 121-214, 90-198 and 21-34 mg/kg DM respectively (Nicholson et al., 1999). The Zn and Cu concentrations were 105.7 and 19.8 mg/kg DM in pig manures (Hao et al., 2008). The Zn and Cu concentrations in pig manures were 554 ± 747 and 71 ± 119 mg/kg DM respectively (Menzi and Kessler, 1998). There were, however, wide variations in Zn and Cu concentrations 128 ± 981 and 22 ± 1575 mg/kg DM in pig manures (Nicholson et al., 1999).

The objective of the study was to quantify nutrients and heavy metals (N, P, K, Mg, Cu, Zn) fluxes in i) the agricultural system (small scale pig farms), and ii) the downstream aquacultural system (piggery waste-fed fish ponds). The study was conducted with a view to quantifying nutrients released to the environment as a result of farming and estimating the assimilative capacity of the surrounding environment.

METHODS

Study area

Small scale pig farms in the peri-urban Pathum Thani province (Fig. 1) near Bangkok were selected as they were considered typical of up to a third of pig farms of the country. Managerial information on pig production in the study area was collected by personal visits, interviews with related parties, on-farm monitoring and sampling analysis in AIT [please define] laboratory. Samples were collected monthly from the selected farms, and nutrient and heavy metal levels were determined. Twenty-six small pig farms (with a total of 3,600 pigs) are located in a cluster which, because of their proximity to each other, allowed considerion of this group as a medium-scale farm. The productive periods of pig and fish farming are quite similar. There were two cycles of pig production: January to May and July to November.

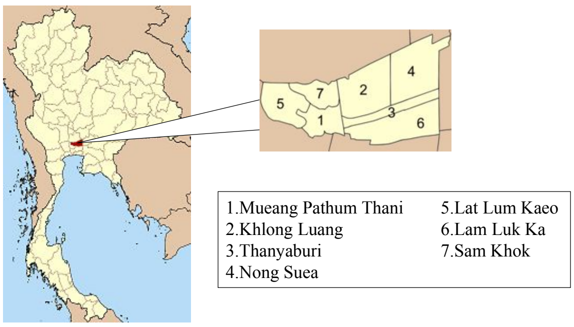

Fig. 1 Study area in Central Thailand

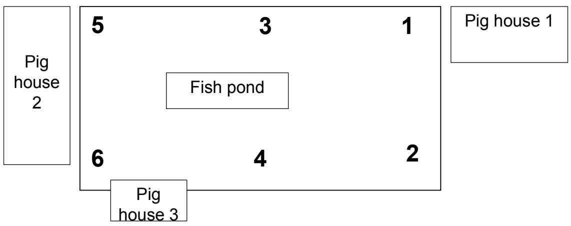

Fig. 2 IAA-system schematic with six pond sampling points

Sample collection

We aimed to quantify the amount of nutrients released as a result of farming and estimate the assimilative capacity of the surrounding environment. Nutrient inputs (feed) and releases through pig manure were sampled monthly in the fattening period (about 6-7 months) to provide information on the environmental load in that period. Samples were taken for nutrient and dry matter analysis for each type of input. Fish pond water and sediment were sampled monthly to provide information of nutrient flux and environment load due to the use of pig manure as fish feed.

Sample analysis and calculation

DM content was determined for all feed, manure samples and sediment samples according to standard methods (APHA, 2005). A 100 gram (g) (fresh weight) sub-sample of each feed was dried and milled. Then 1 g of the dried material was analyzed by acid digestion and analyzed for TKN (Total Kjeldahl Nitrogen and Titrimetric Method), P (Persulphate Degestion Method and Colorimetric Method), K, Mg, Cu and Zn (Atomic absorption spectrophotometry). The analysis method for soil and water were applied as follows. One liter of pond water was collected manually from six different points (Fig. 2). The sample was stored in a plastic container and refrigerated at < 4ºC once it reached at the laboratory. Nutrient and heavy metal concentrations (N, P, K, Mg, Cu and Zn) were determined. Pond sediment accumulation was sampled using a tank volume of 2,535 m^3 (0.13x 0.13 m^2 and 0.15 m high), six tanks were place at the pond bottom at the six representative locations (Fig. 2) for one month period. Nutrient and heavy metal concentrations (N, P, K, Mg, Cu and Zn) were determined. The amount of nutrient and heavy metal for each input or output sources was estimated by multiplying weight or volume by nutrient concentrations measured at the nearest date. The data were recorded and prepared for statistical analysis. A spreadsheet program was used for statistical analysis.

The amount of nutrient and heavy metal flux for each input or output sources was estimated as in Eq. (1).

$$\text{Nuflux} = (\text{DW} \times \text{Ncon} \times \text{Np} \times 365) / \text{S} \quad (1)$$

where Nuflux is nutrient or heavy metal flux (kg/ha/yr), DW is dry weight of sample (kg/day/pig), Ncon is nutrient or heavy metal concentration (g/kg or mg/kg of DW of sample), Np is number of pigs per year (pigs/yr), and S is farm area or pond surface area (ha).

RESULTS AND DISCUSSIONS

Nutrients and heavy metal concentration and flux of pig farm and fish pond

Nutrient and heavy metal concentrations and fluxes of pig farms (pig feed and pig manure) and fish ponds (pond water and pond sediment) are shown in Tables 1 and 2. The amount of nutrient and heavy metal flux for each input or output source was estimated by multiplying weight or volume by nutrient concentrations measured at the nearest date.

Pig production

Average total numbers of pigs in the study farm in the area of 12,800 m^2 were 570 pigs per year consisting of piglets, fattening pigs and sows (240, 230 and 100 pigs, respectively). Fattening pigs and sows were fed with *mixed food waste and milk powder* while piglets were fed with commercial feed. The DMs of piglet feed and fattening feed were 87.18 and 19.70% of wet weight, respectively. The DMs of piglet, fattening and sow manure were 21.6, 24.5 and 41.2% of wet weight, respectively. The DM of pond sediment was 6.9% of wet weight.

Fish production

The size of the pond was 2,300 m^2 (20m x 115m) with an average depth of 1 m. The pond receives pig manure as feed from 285 pigs in each cycle of pig production (570 pigs per year). Before stocking the fish, pond sediment from the previous fish crop was removed and applied to dikes adjacent to the pond. Pig manure is only one source of input to the pond (excluding rain water). Possible predators or unwanted animals were eradicated with quick lime. The average weight of stocked catfish was 3-5 g with approximately 44 fish/ m^2 (100,000 fish). The sediment accumulation rate in the fish pond was 2.40 ± 0.15 (mg/L/d).

Table 1 Nutrients and heavy metal concentrations of pig production and fish production

Type of Sample		N (g/kg dm)	P (g/kg dm)	K (mg/kg dm)	Zn (mg/kg dm)	Cu (mg/kg dm)	Mg (g/kg dm)
Piglet feed	Mean	30.48	6.74	6.05	216.87	93.12	1.46
	Range	27.41 – 33.19	4.95 – 7.96	3.74 – 8.73	87.82 – 641.59	9.82 – 172.21	0.53 – 1.93
Fattening feed	Mean	45.61	3.75	7.04	25.38	2.31	1.50
	Range	36.45 – 53.83	3.09 – 4.53	5.79 – 8.88	18.01 – 33.54	< 0.01 – 7.88	1.15 – 1.70
Piglet manure	Mean	35.47	20.15	7.98	721.65	650.86	1.41
	Range	32.60 – 38.20	11.06 – 31.03	3.49 – 14.06	<0.005 – 1246.13	416.00 – 993.42	0.76 – 1.89
Fattening manure	Mean	38.80	13.64	7.92	134.45	24.51	1.35
	Range	33.46 – 43.38	11.23 – 18.62	4.49 – 11.20	94.27 – 183.93	5.09 – 42.78	0.81 – 1.99
Sow manure	Mean	32.46	35.15	5.43	1173.84	40.21	1.22
	Range	17.30 – 41.89	26.73 – 43.37	3.69 – 8.14	80.87 – 1796.30	16.23 – 68.29	0.60 – 1.94
Pond Sediment	Mean	2.29	2.26	4.82	45.00	15.37	1.25
	Range	1.23 – 4.00	0.75 – 6.96	0.06 – 7.43	20.06 – 100.58	< 0.01 – 47.77	0.09 – 1.75
Pond Water (mg/L)	Mean	72.93	28.08	42.42	0.12	0.005	15.42
	Range	39.76 – 85.12	10.33 – 44.63	34.00 – 48.00	0.01 – 0.27	< 0.01	14.10 – 17.20

Where samples were below the limit of detection (LOD), a value of 0.5 x LOD was used to calculate means (LOD = 0.005 and 0.01 for Zn and Cu respectively).

Table 2 Nutrient and heavy metal flux of pig production and fish production (in kg/ha/year)

Type of Samples	N	P	K	Zn	Cu	Mg
Feed						
Piglet	6060 ± 1261	1361 ± 412	1.2 ± 0. 5	49 ± 46	20 ± 14	303 ± 144
Fattening	3989 ± 1043	327 ± 77	0.6 ± 0.2	2.2 ± 0.8	0.3 ± 0.7	131 ± 32
Sow	2128 ± 340	175 ± 23	0.3 ± 0.08	1.2 ± 0.3	0.1 ± 0.3	7 ± 10
Manure						
Piglet	157 ± 52	103 ± 67	0.04 ± 0.03	4 ± 3	3 ± 1.9	7 ± 3
Fattening	219 ± 70	80 ± 37	0.04 ± 0.02	0.8 ± 0.4	0.16 ± 0.13	8 ± 5
Sow	138 ± 37	155 ± 64	0.02 ± 0.01	5 ± 3	0.19 ± 0.12	5 ± 3
Sediment	2945 ± 846	2885 ± 2516	6 ± 2	55 ± 22	19 ± 16	1513 ± 397
Pond water	1.4 ± 0.3	0.6 ± 0.3	0.8 ± 0.04	0.002 ± 0.001	0.0001 ± 0.0	0.30 ± 0.02

Nutrients and heavy metal concentration and flux

Nutrient and heavy metal fluxes vary widely in amount and composition, depending on age of pig and type of feed. In addition, the type of operations management practices and climate are important influences.

High ambient temperatures generally produce weaker waste because the pigs drink more water. Appropriate management of livestock can minimize the negative and support the positive effects on the environment. Area-wide integration (AWI) between specialised livestock and crop farms in the framework aims at re-establishing the balance between livestock and crop production on a regional level in Thailand (AWI 2001). The manure contents of the study samples were significant lower than AWI standards (Table 3). This may be due to the lower nutrient concentrations in pig feed.

Table 3 Content of manure in this study compared to AWI (2001)

Pig category		Content of manure[1] (kg/head/year)	Results from the study (kg/head/year)
Sow	N	31.200	1.77 ± 0.48
	P	16.100	1.99 ± 0.83
	K	12.100	0.00032 ± 0.00016
	Mg	2.400	0.07 ± 0.05
	Cu	0.007	0.00245 ± 0.00159
	Zn	0.100	0.07151 ± 0.04675
Fattening pig	N	12.500	1.22 ± 0.39
	P	5.600	0.45 ± 0.21
	K	4.800	0.00027 ± 0.00015
	Mg	1.000	0.05 ± 0.03
	Cu	0.0025	0.00092 ± 0.00072
	Zn	0.040	0.00467 ± 0.00270

[1] *modified from AWI, 2001*

N and P were the major nutrients found in the system. A number of authors have measured Zn and Cu concentrations in pig manures (Nicholson et al., 1999). The ranges from these studies were similar to those found in the present study (Table 1). However, the concentration of Zn and Cu in fattening pig feed was much lower than mill feed and/or concentrated feed, implying that food waste had a lower concentration of Zn and Cu. Consequently the concentrations of Zn and Cu in fattening manure were low.

The studied IAA system is considered to be a closed system: fish pond water has never been discharged during the fish production cycle. Sludge was removed to the banks of the pond and thereby did not contaminate the environment. Flushing water for the pig farms was also pumped from the fish pond. Pond water was refilled from rain or from nearby canals when the level of water dropped due to evaporation. The system has a high efficiency in terms of nutrient use and lower impact on the environment.

Integrated livestock-fish farming systems have recently been introduced to the area in an attempt to provide additional farm income and to increase protein supply for the small-scale farmers. Pig-fish farms can be developed further as medium-scale farms minimizing total investment.

CONCLUSIONS

Nutrient and heavy metal concentration (N, P, K, Zn, Cu, and Mg) of pig feed and manure from these farms are significantly lower than other studies. Nutrient and heavy metal fluxes were studied in (i) the agricultural system (a small-scale pig farm), and (ii) the downstream aquacultural system. Nutrients and heavy metal fluxes in piggery waste-fed fish ponds were quantified. Estimates of nutrient levels and heavy metal fluxes can be used for farm management decisions with a view to decreasing the environmental impacts of piggeries and fish farms. Nutrient and heavy metal flux data of the IAA system could be a basis for developing a practical tool estimating nutrient flux for an integrated agriculture-aquaculture (IAA) system. The described IAA system used by local small scale farmers appears to be a practical option for farm management (for small and medium farms) to the nutrient use efficiency, and less environmental impact.

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