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Evaluation of nitrogen balance on pig/crop farm systems in Jiulong River watershed, China

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Field surplus nitrogen and farm disposal nitrogen (N) are major sources of environmental pollution in farm systems. The purpose of this study was to use nitrogen balances at the field and farm level approaches to estimate the effects of pig production in the Jiulong River watershed, Fujian province, China, on nitrogen losses to the environment on 67 pig farms. The field surplus nitrogen ranged from 6.19 to 18.19 t nitrogen ha^{-1}, which was caused by high pig density and excessive application of manure. Manure application rates of more than 450 to 510 kg nitrogen ha^{-1} would increase the potential nitrate concentration to more than 10 to 20 mg l^{-1}. Therefore, 44 to 48 heads of pig ha^{-1} was suggested to as the environmental capacity for sustaining optimal nitrogen cycling in pig farms in the Jiulong River watershed.

The majority of farms have potential environmental risks because of high farm nitrogen imbalances. With more than a 2:1 ratio of N inputs to outputs, N inputs were 50 percent higher than outputs. Feed was the main input source, while pig production and manure exported were the major managed outputs. Based on the farm nitrogen balance calculation, the management options that would contribute to a more favorable nitrogen balance were also identified.

Keywords: environmental risk, nutrient surplus, loss

Introduction

Livestock production systems are a major source of nitrogen pollution affecting the quality of water and air resources (Williams, 1995). Primary concerns are nitrate contaminations in groundwater, nitrate and ammonium contamination of surface water, and ammonia loss to the atmosphere. Livestock and humans in China produced 16.42 million tons of plant-available N in 1998, 66.3% of which was lost into the environment (Zhu, 2003). In the intensive livestock operation region, N losses are more severe than in other places. Livestock producers have a growing responsibility to manage for a balanced N system in order to reduce N losses.

Solutions to N related issues require an understanding of the N flows on livestock farms (Figure 1). Nitrogen balances are increasingly used as a tool to define N flows of a farm. The difference between N inputs to the farm via chemical fertilizer feed and outputs via animal products and crops are indicators of environmental risk. These surplus outputs are either lost to the environment directly or added to N reserves in the soil, increasing the risk for future environmental losses (Klausner, 1995). Achievement of balance between the N inputs and managed outputs is the key to minimizing

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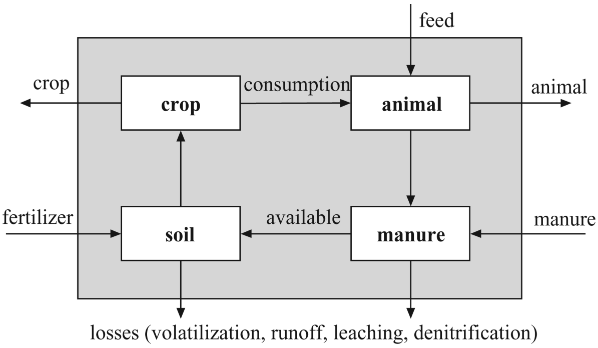

Figure 1. Conceptual N-flow model in a livestock farm system.

the N-related environmental risk associated with livestock production.

An imbalance or accumulation of N on livestock operations is reported to be a driving force behind the potential environmental risk (Klausner, 1995). The imbalance between total N inputs and managed outputs was observed to be 59 to 79% for 17 New York dairies (Klausner, 1995), and 44.4 to 58.5% for 33 Nebraska livestock farms (Koelsch and Lesoing, 1999). The percentages indicate the portion of N in the inputs that is not accounted for in the managed outputs. A mass N-balance model by Smolen et al. (1994) for Texas (a large beef population) and Adair (a large poultry population) counties in Oklahoma suggested an annual N imbalance within these counties of 51% (12,400 t) and 53% (2,400 t) from imported N, respectively.

Some recent studies have indicated that field surplus N is a good estimator of N discharged from fields. Hayashi and Hatano (1999) showed that the annual surplus in an onion field in central Hollaido, Japan, corresponded to the annual nitrate discharge measured in tile drainage. Barry et al. (1993) indicated that the field surplus N provided a good prediction of mean nitrate concentration in soil drainage water. However, the amount of discharged N measured for the large-scale watersheds were significantly less than the estimated field surplus N, probably due to denitrification and N uptake by trees in the riparian zone (David et al., 1997). Therefore, field surplus N is not a factor of the actual loss over the given period, but expresses the potential N loss from a farm over time if stocking rate or crop rotation is not changed significantly.

The Jiulong River watershed of southeastern China is characterized by intensive agricultural management (i.e., nutrient inputs, high stocking rate and crop yields). The significant economic benefits from vertical coordination and a geographic concentration of livestock production led to both larger and more concentrated operations. Nitrogen is directly discharged from pig farms and pollutes the environment if the N management exceeds the environmental capacity in the farm systems. The purpose of this study was to evaluate the N balance on pig farm systems of Jiulong River watershed to calculate the environmental risk and identify the characteristics or management practices that minimize the imbalance of N.

Materials and methods

Study area

Jiulong River watershed is located in Fujian province, China. It is a subtropical monsoon area of eastern Asia. Annual mean temperature and precipitation rates are 19.9 to 21.1°C and 1 400–1 800 mm, respectively. The annual cultivation period is about 300 to 330 d. Therefore, climatic and site conditions are suitable for crop and animal production. Since the 1990's, pig production pollution has been the most significant environmental concern of this watershed. While livestock numbers were increasing, available cropland operated by confined operations on which to spread manure declined. This reduction in land per animal unit has raised concerns that nutrients in manure are not being utilized by plants and are increasingly becoming more likely to run off or to leach into water resources. Sometimes wastewater from the barn was directly discharged into waters.

As official data on import and export of N are not available on the farm scale, a personal visit was made to each farmer of the 67 'pig/crop' farms, during which the desired information was collected. A preliminary N balance was established in July 2003.

N balances

Two methods are available to estimate the losses or surplus of N from pig farms. Farm gate balances (FGBs) are defined as the difference between N-input and N-output at the farm level (i.e., the whole farm is treated as a black box; Figure 1). The balance entries of the FGB were based on the mineral accounting system currently used in The Netherlands (Van Beek et al., 2003). The balance entries not included in the FGB (e.g., those incorporated in the surplus) are atmospheric deposition, ammonia volatilization, denitrification, leaching and net mineralization. In this study the N imbalance is expressed as a ratio of N inputs to outputs to provide a more direct measure of the relationship between inputs to outputs. For example, an

Table 1. Nitrogen concentrations and assumptions used for estimating nitrogen balance. *BW = body weight (value provided by producer).

Nitrogen inputs/outputs	Concentration	Reference
Pig body	N = 2.32 to 2.52% of BW*	Kyriazakis and Emmans, 1991
Feed	2.9%	Liao, 1998
Crop	1.06%	Ryusuke et al., 2002
Fruit	0.23%	Zhang, 2004
Ammonium carbonate	17%	Measured
Urea	46%	Measured
Manure	0.6%	Measured
Composting manure	2.65%	Measured

input-to-output ratio of 2:1 suggests that twice as much N is being brought onto the farm as leaves the farm in managed products. It also implies that 50% of the inputs are added to the environment (air, water, or soil). The value is calculated as follows:

$$\text{N imbalance ratio} = \frac{\text{Inputs} + \text{Change in input inventory}}{\text{Outputs} + \text{Change in output inventory}} \quad (1)$$

Field surplus N is defined as the difference between N inputs and N outputs at the field level (Ryusuke et al., 2002). The field is the calculation boundary (Figure 1). The surplus is estimated by the as follows:

$$\begin{aligned}\text{Field surplus N} &= \text{chemical fertilizer N} + \text{manure N}\\ &+ \text{atmospheric deposition N} + \text{N fixation}\\ &- \text{ammonia volatilization from manure application}\\ &- \text{denitrification} - \text{crop N uptake.} \qquad (2)\end{aligned}$$

All the surplus calculations were accounted on a yearly basis. N contents in imports of feed and fertilizers, exports of pigs, crops, fruits, manure and composting manure were calculated by multiplying the dry or fresh weight values investigated and N content values measured or assumed (Table 1). Manure N was assumed to be 80% of intake N based on McKown et al. (1991). The amount of ammonia volatilized during storage and application was assumed to be 38% of total N in manure (Barry et al., 1993). Denitrification was estimated as 20% of ammonium applied (Ryden, 1983). Atmospheric deposition of N was measured to be 44.6 kg N ha^{-1} y^{-1}. The relationships among the N balances were found out by regression analysis using SPSS software.

Estimation of potential nitrate concentration

Assuming that all field surplus N in a pig farm land is leached away after mineralization and nitrification each year, the annual mean nitrate concentration in drainage water from fields was predicted by dividing the amount of field surplus N by drainage water volume (Ryusuke et al., 2002). Drainage water volume was approximated as the difference between mean annual precipitation (1600 mm) and evapotranspiration (1250 mm). The mean annual drainage water volume was approximately 350 mm. This value is used with the predicted N surplus from N balances to calculate potential concentration of nitrate in streams.

Results

Characteristics of pig/crop farms surveyed

The average characteristics for all of 67 pig farms are summarized in Table 2 in three size groupings; 1) less than 200 animal units, 2) 200 to 1,000 animal units, and 3) more than 1000 animal units. One animal unit is defined as 100 kg of average body weight. The stocking rate, field surplus N, and farm imbalance ratios of the

Table 2. Average characteristics and nitrogen balances for 67 pig farms in the Jiulong River watershed.

Item	<200 animal unit	200–1000 animal unit	>1000 animal unit
Number of farms	27	23	17
Animal unit (100 kg)	88	434	2540
Stocking rate/heads ha^{-1}	705	2125	2034
Field surplus N, t N ha^{-1}	6.2	18.2	14.9
Farm surplus N, t N ha^{-1}	9.2	30.1	25.5
Purchased feed N, Input N	0.982	0.999	0.999
N imbalance ratio (Inputs/Outputs)	2.79	2.97	2.67

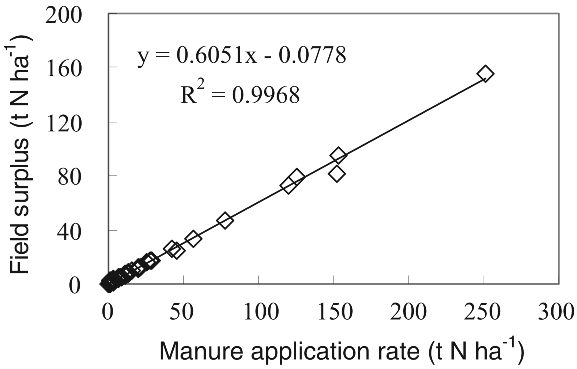

Figure 2. Relationship between manure application rate (t N ha^{-1}) and field surplus N (t N ha^{-1}).

farm with 200 to1000 heads were the highest among the three farm sizes.

Relationships among the N balances at the field and farm level

Field surplus-N was significantly correlated with manure application rate (Figure 2). The equation is $y = 0.6051x - 0.0778$ ($R^2 = 0.9968$, $F = 20313$, $P < 0.01$). The pig density is also strong correlated with manure application rate as follows: $y = 0.0137x - 0.1509$ ($R^2 = 0.9931$, $F = 9312$, $P < 0.01$; Figure 3). Therefore, high stocking results in the excessive application of manure. The pig density and drainage water was also significant with the estimated potential nitrate concentration as follows: $y = 2.3577x - 24.6189$ ($R^2 = 0.9808$, $F = 3312$, $P < 0.01$) (Figure 3). This showed that when pig density increased to 44 to 48 heads ha^{-1}, the potential nitrate concentration was 10 to 20 mg l^{-1}, which is the maximum allowable concentration for potable water recommended by the World

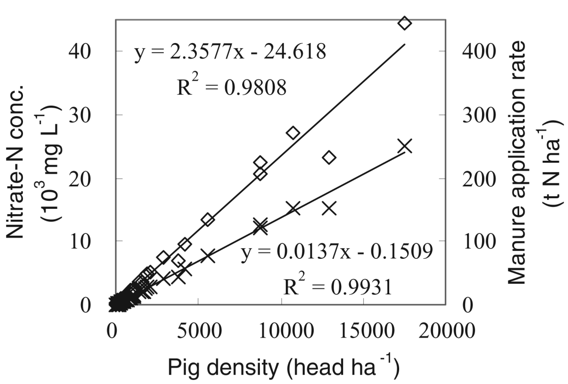

Figure 3. Relationship between pig density (head ha^{-1}) and manure application rate (t N ha^{-1}) and nitrate concentration (mg l^{-1}) (◇ nitrate concentration; ×manure application rate).

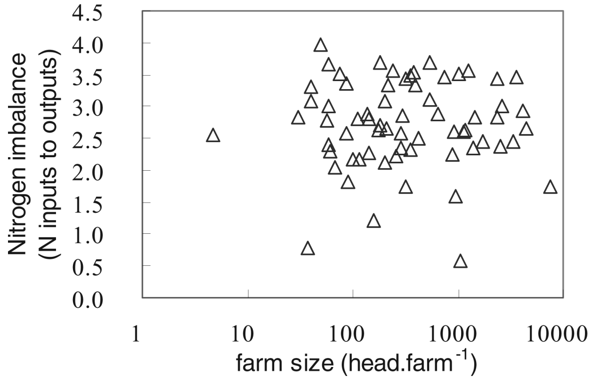

Figure 4. Relationship between farm size and nitrogen balance.

Health Organization and China's government, respectively. Correspondingly, the application rate was 450 to 510 kg N ha^{-1} when pig density increased to 44 to 48 heads ha^{-1}.

Figure 4 shows the N balance for study farms. In all cases, the inputs were greater by at least twice the outputs. This indicates that feed and fertilizer inputs need to be adjusted. Alternatively, to bring the farm into balance, more land needs to be acquired or the manure has to be transferred to other sites.

In the study of 67 pig/crop operations in Jiulong River watershed, operation size did not affect the input: output ratio ($R^2 = 0.1280$). High and low risk operations were found in all size classes.

Figure 5 shows the relationship of N imbalance and the ratio of manure to total managed outputs. N imbalance was negatively related to the ratio of manure exported as follows: $y = -2.2657x + 2.8811$ ($R^2 = 0.4001$, $F = 17.27$, $P < 0.01$). The larger the ratio of manure to total managed output, the smaller the N imbalance is. This means that manure export from farms would contribute to a sustainable nitrogen balance.

The N imbalance was positively correlated with the proportion of pig production in the total managed

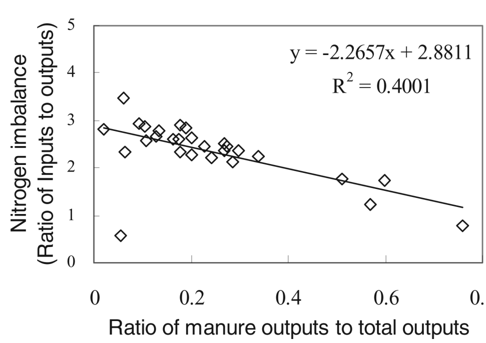

Figure 5. Relationship between ratio of manure outputs to total outputs and nitrogen imbalance.

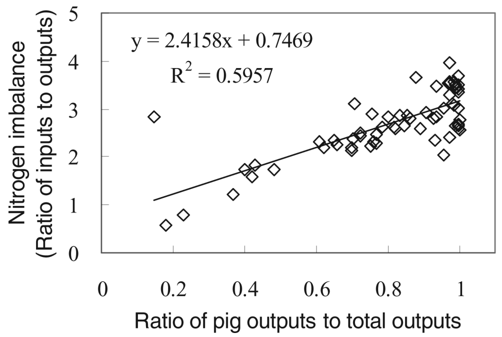

Figure 6. Relationship between ratio of pig outputs to total outputs and nitrogen imbalance.

output: $y = 2.4971x + 0.7241$ ($R^2 = 0.4837$, $F = 61$, $P < 0.01$; Figure 6). The distribution of managed N outputs from a farm (animal products, marketed crops, and exported manure) provides some indication of the relative importance of crop and livestock production within a system. As pig products represent an increasing part of the products marketed from a farm, the nutrient imbalance was observed to increase in the 67 observed farms. The environment is protected if nutrients are used efficiently in crop production. If farmers pay more attention to the pig production in whole system, a resulting environmental impact is more likely. Therefore, nutrient imbalance grows with greater emphasis on animal production in Jiulong River watershed.

Discussion

This study highlights several key problems relative to N management within pig/crop farms in Jiulong River watershed. First, field surplus N (6–18 t N ha^{-1}) is much higher than the results obtained by Halberg (1999) for dairy farms in Denmark (180 kg N ha^{-1}) and at the experimental farm 'De Marke' in the Netherlands (166 kg N ha^{-1}; Aarts et al., 2000). The high N surplus values within individual farms were attributed to animal intensification, particularly pig production, which does not require a local land base for feed production. De-coupling of feed production and animal production resulted in the concentration of N within a limited geographical area to levels well beyond the ability of the local agricultural land base to use efficiently. The potential for animal intensification to increase the risk of nitrate leaching has been reported elsewhere (Power and Schepers, 1989). Based on the calculation of Zebarth et al. (1995), a surplus of 100 kg ha^{-1} nitrate in the soil root zone may result in greater than 10 mg l^{-1} nitrate in groundwater in this area. Therefore, pig/crop farms can have a significant impact on the environment in this study site.

In the present study, with a pig density of 44 to 48 heads ha^{-1}, the potential nitrate concentration was above 10 to 20 mg l^{-1}, the drinking water limits. Therefore, 450 to 510 kg N ha^{-1} is the maximum manure application rate to sustain optimal N cycling under present operating conditions. This value is higher than the results obtained by Ryusuke et al. (2002; 160–185 kg N ha^{-1}), and Yuan et al. (2000; 400 kg N ha^{-1}). This could be due to the planting of fruit with high N requirements on these study sites.

Whole farm balance evaluation shows the majority of pig farms in the Jiulong River watershed have high potential environmental risks. Whole farm N balances provide some advice for N management, including input-output ratios needed to improve. The original sources of these N inputs are also clearly identified, which in turn suggest management strategies for reducing excessive N inputs or options for increasing N outputs.

Purchased livestock feeds were an important source of the N inputs (Table 2). The levels of purchased livestock feed contribution to the total farm N inputs are higher than that observed by other studies (Klausner, 1995; Koelsch and Lesoing, 1999). Increasing the livestock digestion to reduce feed N inputs is an alternative strategy. Chemical fertilizer was an insignificant N input for the studied farms, so farms will gain little environmental benefit from more efficient utilization of chemical fertilizers.

In this study, marketing of manure creates a new management option, similar to the sale of pig products or crops. Other studies also address the importance of marketed manure to improve N balances (Ribaudo et al., 2003). Many operations might address their manure management problems by selling it, or giving it to farmers who don't have enough organic fertilizers.

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References

Aarts, H. F. M., Habekotte, B., Van Keulen, H., 2000. Nitrogen (N) management in the 'De Marke' dairy farming system. Nutr. Cycl. Agroecosyst. 56, 231–240.

Barry, D. A. J., Goorahoo, D., Goss, M. J., 1993. Estimation of nitrate concentrations in groundwater using a whole farm nitrogen budget. J. Environm. Qual. 22, 767–775.

David, M. B., Gentry, L. E., Kovacic, D. A., Smith, K. M., 1997. Nitrogen balance in and export from an agricultural watershed. J. Environm. Qual. 26, 1038–1048.

Halberg, N., 1999. Indicators of resource use and environmental impact for use in a decision aid for Danish livestock farmers. Agriculture, Ecosyst. Environm. 76, 17–30.

Hayashi, Y., Hatano, R., 1999. Annual nitrogen leaching in subsurface-drained water from a clayed aquic soil growing onions in Hokkaido, Japan. Soil Sci. Plant Nutr. 45, 451–459.

Klausner, S., 1995. Nutrient management planning. In: K. Steele (Ed.), *Animal Waste and the Land-Water Interface*, pp. 383–392. Lewis Publishers, New York.

Koelsch, R., Lesoing, G., 1999. Nutrient balance on Nebraska livestock confinement systems. J. Anim. Sci. 77, 63–71.

Kyriazakis, I., Emmans, G. C., 1991. Diet selection in pigs: dietary choices made by growing pigs following a period of underfeeding with protein. Anim. Prod. 52, 337–346.

Liao, X., 1998. *Technology of Wastewater Treatment of Intensive Pig Confinement*. Chinese Agricultural Pulisher, China.

McKown, C. D., Walker, J. W., Stuth, J. W., Heitschmidt, R. K., 1991. Nutrient intake of cattle on rotational and continuous grazing treatments. J. Range Manage. 44, 596–601.

Power, J. F., Schepers, J. S., 1989. Nitrate contamination of groundwater in North America. Agricult. Ecosyst. Environm. 26, 165–187.

Ribaudo, M. O., Gollehon, N. R., Agapoff, J., 2003. Land application of manure by animal feeding operations: is more land needed? J. Soil Wat. Conserv. 58(1), 30–38.

Ryden, J. C., 1983. Denitrification loss from a grassland soil in the field receiving different rates of nitrogen as ammonium nitrate. J. Soil Sci. 34, 35–365.

Ryusuke, H., Takuro, S., Zheng, T., Masahiko, O., Li, Z., 2002. Nitrogen budgets and environmental capacity in farm systems in a large-scale karst region, southern China. Nutr. Cycl. Agroecosyst. 63, 139–149.

Smolen, M. D., Storm, D. E., Peel, D., Kenkel, P., 1994. Mass balance analysis of nutrient flow through feed and waste in the livestock industry in the southern plains. Great Plains Animal Waste Conference on Confined Animal Production and Water Quality, pp. 168–174. National Cattlemen's Association, Englewood, CO.

Van Beek, C. L., Brouwer, L., Oenema, O., 2003. The use of farmgate balances and soil surface balances as estimator for nitrogen leaching to surface water. Nutr. Cycl. Agroecosyst. 67, 233–244.

Williams, P., 1995. Animal production and European pollution problems. Anim. Feed Sci. Techn. 53, 135–144.

Yuan, X., Tong, Y., Yang, X., Li, X., Zhang, F., 2000. Effects of organic manure on soil nitrate nitrogen accumulation. Soil Environm. Sci. 9(3), 197–200.

Zebarth, B. J., Liebscher, B. H., Chipperfield, K., 1998. Agricultural land use practices and nitrate contamination in the Abbotsford Aquifer, British Columbia, Canada. Agriculture. Ecosyst. Environm. 69, 99–112.

Zhang, K., Gao, H., 2004. *Treatment and Disposal of Wastewater from Animal Production*. Chemical Industry Press, China.

Zhu, Z. L., 2003. Fertilizer management strategies for the harmonization of agriculture development with environment protection. J. Chinese Inst. Sci. 2, 89–93.