Assessing three nitrogen use efficiency indicators for pig supply chains in East and Southeast Asia

Aimable Uwizeye[1,2,3*], Pierre J. Gerber[1,2], Rogier P.O. Schulte[3], Imke J.M. de Boer[1]

[1] Animal Production Systems group, Wageningen University, PO Box 338, 6700 AH, Wageningen, the Netherlands
[2] Food and Agriculture Organization of the United Nations, Animal Production and Health Division, Viale delle Terme di Caracalla, 00153 Rome, Italy
[3] Teagasc – Crops, Environment and Land Use Programme, Johnstown Castle, Wexford, Ireland

Abstract

Pig supply chains are developing rapidly in East and Southeast Asia (ESEA), fuelled by population growth, growing incomes and urbanization that lead to increased demand for animal produce. Pig supply chains, however, are associated with losses of reactive nitrogen (Nr) to the environment at various stages of the chain. To benchmark livestock supply chains and identify improvement options, we previously developed a framework to assess Nr use efficiency at chain level. This framework compromises three indicators: life-cycle nitrogen use efficiency (life-cycle-NUE_N), life-cycle net nitrogen balance (life-cycle-NNB_N), and nitrogen hotspot index (NHI_N). The aim of this study is to apply these three indicators to pig supply chains in ESEA. Preliminary results showed that the computed Life-cycle Nr use efficiency indicators vary greatly between backyard, intermediate and industrial supply chains. Industrial supply chains had relatively higher estimates of life-cycle-NUE_N than intermediate and backyard supply chains. Our data showed a negative relationship between life-cycle-NNB_N and NHI_N demonstrating the presence of hotspots of Nr losses in backyard and intermediate supply chains, as compared to industrial supply chains. These differences between supply chains result from differences in the origin of feed material, feed conversion, manure management system and animal health status. This study demonstrates that there is a scope to improve the Nr use efficiency in pig supply chains in ESEA, especially by focusing on the optimization of fertilization of local feed crops and manure management systems. Further research is required to assess the potential effectiveness of each of these interventions.

Key Words

Hotspots, life-cycle, pig supply chain, reactive nitrogen

Introduction

The production from pig supply chains in East and Southeast Asia (ESEA) has increased over the last 50 years, with an average annual growth rate of 3%. The ESEA pig population is estimated to have reached 578 million head in 2014, with China contributing 82% of the total (FAOSTAT, http://faostat3.fao.org/home/E). Pig supply chains effectively contribute to the supply of meat to a growing population in Asia, but also contribute to losses of reactive nitrogen (Nr) to the environment, such as ammonia or nitrate. In particular, the development of a large scale intensive pig operations mainly near larger cities has led to cases of continuous discharge of manure into surface water, high ammonia volatilization, and nuisance odor (Gerber and Menzi, 2006). In China, for example, it is estimated that between 20% and 60% of manure is discharged to water (Strokal et al., 2016), with negative impacts such as water pollution or aquatic biodiversity loss. Several studies have investigated Nr losses to the environment at a regional or country level (Chen et al., 2011; Gerber and Menzi, 2006; Yamaji et al., 2004). No study, however, has yet explicitly quantified the Nr use efficiency of pig supply chains. Recently, Uwizeye et al. (2016) developed a framework to assess Nr use efficiency at chain level. This framework includes three complementary indicators: the life-cycle nitrogen use efficiency (life-cycle-NUE_N), the life-cycle net nitrogen balance (life-cycle-NNB_N), and the nitrogen hotspot index (NHI_N). The objective of this study is to quantify these Nr use efficiency indicators for pig supply chains in ESEA, with a view to identifying potential interventions to improve nutrient management.

Methods

Description of pigs supply chains

We evaluated three types of pig supply chains in ESEA, ranging from the small-scale backyard supply chains, which use low levels of input such as feed or energy, to large-scale chains that are market-oriented and industrialized (Seré and Steinfeld, 1996). The backyard supply chain represents 56% of total pig population in ESEA and accounts for over 80% of national pig population in some countries such as Cambodia. It is characterized by pigs that are housed in simple pens or are kept free-range. The pigs' diet is derived mainly through scavenging and from swill from households. In this system, pigs are integrated with other livestock species such as ducks or fish. Nutrients in excreted manure are deposited as fertilizer to the cropland, as feed to fish ponds, or discharged into surface water (Gerber and Menzi, 2006; Schaffner et al., 2009). The intermediate supply chain represents 24% of total pig population in ESEA and is rapidly growing in both rural and urban areas, supplying pigs to local markets. Pigs are housed in simple and partially enclosed pens. 20-50% of feed intake is based on locally produced feed, with a considerable share of swill

(MacLeod et al., 2013), whereas the remainder is based on imported feeds. Manure management is less developed, and a small share of manure is applied to cropland; the remainder is discharged into surface water (Gerber and Menzi, 2006; IAEA, 2008; Schaffner et al., 2009). The industrial supply chain represents 20% of total pig population in ESEA, and in some countries such as Malaysia, Thailand or the Republic of Korea, this supply chain is predominant. Pigs are housed in a confined house and are fed mainly with imported feed. Water and energy consumption are usually high. This supply chain produces pig meat for large cities and for export. Production units are highly specialized and generally equipped with effective manure management systems, including storage facilities and biogas generators. Manure is mainly treated in lagoons before transportation to cropland or discharge into the environment (Gerber and Menzi, 2006).

Model concept for life-cycle nitrogen use indicators
The framework developed by Uwizeye et al. (2016) allows the assessment of Nr flows in crop production, animal production, and processing and includes internal processes, loops and recycling of Nr. The three indicators are estimated based on the following matrix: nutrient uptake at each process (PROD), internal nutrient supply to each process (INP), nutrient imports from other food systems to each process (IMP), changes in nutrient stocks at each process (SC) and nutrients mobilized from the nature or other livestock supply chain to each stage (RES). Thus, at a country supply chain level, the Nr use efficiency (NUE_N) at each stage is calculated as follows:

$$NUE_i = \frac{PROD_i + SC_i}{INP'_i + IMP'_i + RES_i} \quad \text{(Eq. 1)}$$

The life-cycle-NUE_N is calculated as follows:

$$RES^*_i = RES_i \,.\left(PROD_i - INP_i - \mathrm{IMP}_i + \widehat{SC_i}\right)^{-1} \quad \text{(Eq. 2)}$$

$$\textit{Life-cycle-NUE} = 1/RES^*_{processing} \quad \text{(Eq. 3)}$$

where $RES^*_{processing}$ refers to the amount of Nr mobilized to produce 1 kg of Nr in end-products at the processing stage.
The life-cycle-NNB_N is expressed as kg Nr losses per area of land used (ha) and is calculated as follows:

$$\textit{Life-cycle-NNB} = \frac{\sum NNB_i \; x \; AF_i}{A} \quad \text{(Eq. 4)}$$

where NNB_i refers to Nr losses at i-th stage, AF_i refers to the biophysical allocation factor between co-products at i-th stage, and A refers to the total land used at a supply chain level.
Finally, NHI is calculated as follows:

$$NHI = \frac{\sigma_{(NNBi)}}{\mu_{(NNBi)}} x \; 100 \quad \text{(Eq. 5)}$$

where σ is the standard deviation of NNB for all i-th stages of a supply chain, and μ is the corresponding average of NNB for all i-th stages of a supply chain. A detailed description of this framework can be found in Uwizeye et al. (2016).

Data and statistical analysis
Data on Nr flows for pig systems were obtained from the second version of the Global Livestock Environmental Assessment Model (GLEAM) (FAO, 2016), with a reference year of 2010. The database contains detailed country-specific data on synthetic fertilizer application, crop residues, manure applied, manure recycled, feed resources, feed rations, pigs number, herd structure, manure management systems, emissions factors and slaughterhouse activities.

Results and discussion
Our estimates for the life-cycle Nr use indicators vary greatly between backyard, intermediate and industrial pig supply chains (Figure 1). Highest life-cycle-NUE_N were derived for the industrial supply chain (ranging from 48% in the Republic of Korea to 69% in the Philippines), intermediate values for the intermediate supply chain, (ranging from 50% in the Republic of Korea to 62% in Malaysia), and lowest values for the backyard supply chain (ranging from 35% in China and Vietnam to 65% in the Philippines). This overall trend is however not observed in all countries: for example, for the backyard supply chain in the Philippines greater life-cycle-NUE_N values were computed than for the two larger-scale supply chains. In general, differences between intermediate and industrial supply chains were smaller than differences between

intermediate and backyard supply chains, as a result of improved manure management, animal health status and feed conversion ratios, as compared to those that apply to backyard supply chains.

Regarding net nutrient balances, our computations assigned the lowest values for life-cycle-NNB_N to industrial supply chains, ranging from 26 kg N ha^{-1} in Timor-Leste to 89 kg N ha^{-1} in the Republic of Korea. This contrasts with ranges from 30 kg N ha^{-1} in Mongolia to 173 kg N ha^{-1} in the Democratic People's Republic of Korea for intermediate chains, and from 35 kg N ha^{-1} in Mongolia to 469 kg N ha^{-1} in China for backyard supply chains. We again observed a negative relationship with NHI_N, demonstrating that losses are more evenly spread across the individual components of the industrial supply chains than is the case for intermediate and backyard supply chain.

The results from our model suggest that Nr inefficiencies were particularly pronounced in the production of local feed crops, for which high nutrient losses were calculated, e.g. 397 kg N ha^{-1} in China. Both synthetic fertilizer and manure are frequently applied in excess to crop requirements, compounded by the fact that the nutrient content of manure is often underestimated (Gerber and Menzi, 2006; Ma et al., 2010). This low Nr efficiency of local crop production reduces the life-cycle-NUE_N of backyard supply chains—which rely predominantly on local feed—more than the life-cycle-NUE_N of other supply chains. These latter chains rely on imported feed and are thus advantaged because of higher crop Nr use efficiency in the regions from which this feed is imported (e.g. Latin America and North America). Furthermore, our models assume that part of the manure from intensive supply chains is spread on non-feed crops and thus exit the livestock systems. This means that subsequent losses are therefore not attributed to the livestock supply chain.

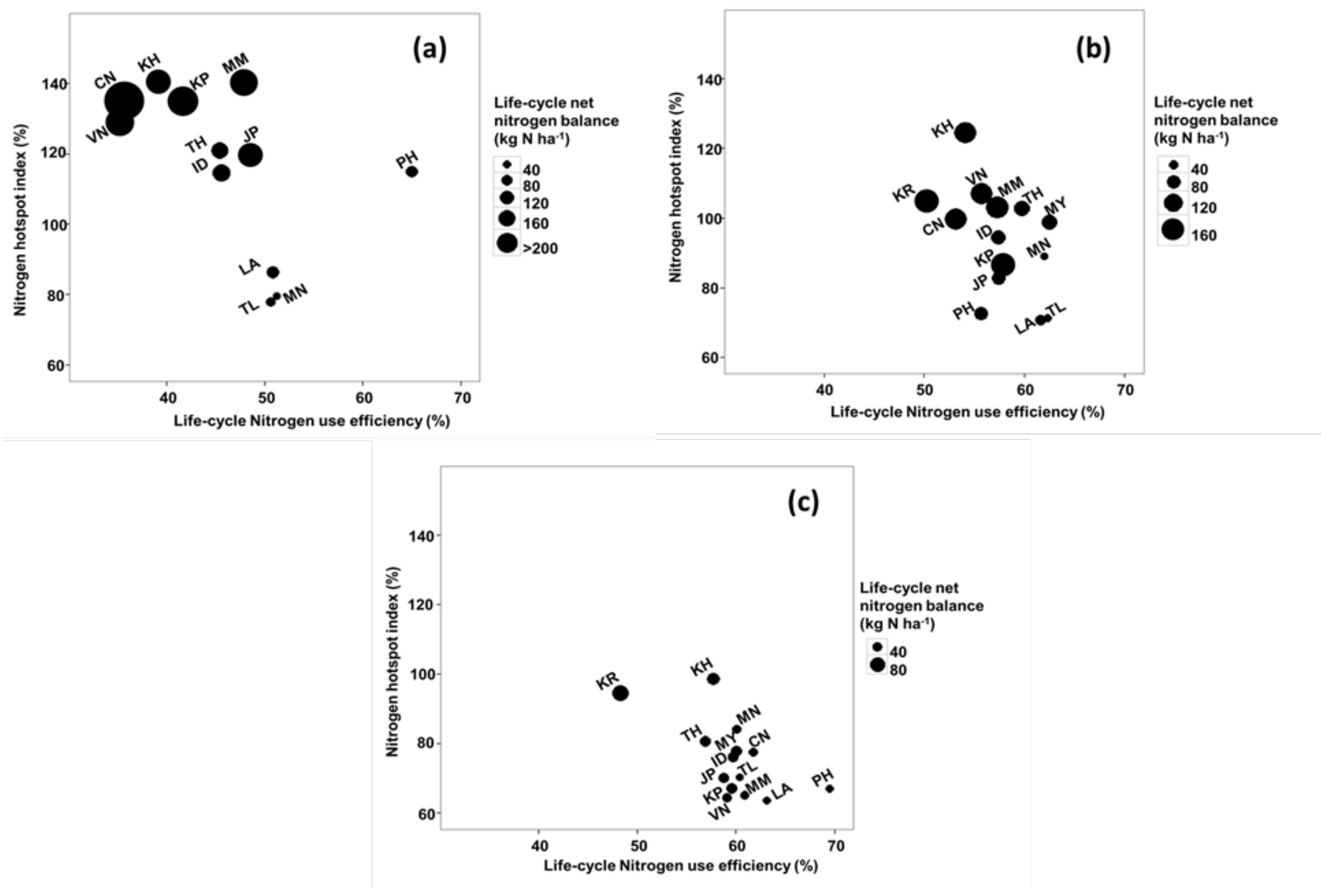

Figure 1: Relationships between computed indicator values for Life-cycle-NUE_N, life-cycle-NNB_N, and NHI_N for pig supply chains in East and Southeast Asia. Letters indicate different production systems: (a) Backyard, (b) Intermediate, and (c) Industrial. Countries are indicated in the plot by their country-acronym: KH: Cambodia, CN: China, KP: The Democratic People's Republic of Korea, ID: Indonesia, JP: Japan, LA: Lao People's Democratic Republic, MN: Mongolia, MM: Myanmar, MY: Malaysia, PH: The Philippines, TH: Thailand, TL: Timor-Leste, KR: Republic of Korea, VN: Vietnam

Our estimates of Nr losses at the animal production stage were low, compared to those at the feed production stage, but may still have high impacts locally, given their point-source nature: a large share of manure is directly discharged into rivers or lost via leaching or overflowing from lagoons (IAEA, 2008; Ma et al.,

2010). Inefficiencies at animal production stage were also computed to be generally greater for backyard systems. The reason is that the manure management system, production efficiencies, and animal health are relatively poor in backyard supply chains, as compared to intermediate and industrial supply chains.
Low Nr losses at the processing stage were computed for all countries and supply chains (1.2 to 4.6 kg N ha^{-1}), although we make note of limited data availability for this stage of the chain. The ubiquity of low losses from the processing stage suggests similar practices of wastewater management, in line with findings by Schaffner et al (2009) in Thailand, where Nr losses were lower at slaughterhouse level, compared to farm level.
In contrast to previous studies, our study allowed for the identification of hotspots of Nr pressures along supply chains and detailed information that can support the design of improvement interventions. For example, in the case of backyard supply chains, our results demonstrate the scope for potential improvements in nitrogen management at the crop production and manure management stage, given the wide variation of NUE observed in these chains. For industrial supply chains, however, potential measures for improved NUE include the recycling of manure on cropland. For intermediate supply chains, potential improvement measures combine those of backyard and industrial supply chains as well as the prevention of manure discharge to surface water.

Conclusion

This study evaluated the efficiency of Nr use in the rapidly developing pig sector of ESEA. Our methodology provides information on the efficiency, the magnitude of Nr losses and the location of these losses along the chain, which are of direct relevance to the design of potential interventions that are required to negate the potential environmental impacts that may arise from the growing pig population in the region. Our study suggests that there is significant scope to improve pig supply chains in ESEA, by focussing on the optimization of Nr use efficiency at crop production stage in backyard and intermediate supply chains, and the animal production stage in intermediate and industrial supply chains. Further research is required to assess the effectiveness and economic implications of contrasting strategies to improve Nr.

References

Chen, N., Hong, H., Huang, Q., Wu, J., 2011. Atmospheric nitrogen deposition and its long-term dynamics in a southeast China coastal area. J. Environ. Manage. 92, 1663–1667. doi:10.1016/j.jenvman.2011.01.026

FAO, 2016. Global Livestock Environmental Assessment Model (GLEAM). Food Agriculture Organization of United Nations. http://www.fao.org/gleam/en/. Accessed 04 April 2016.

Gerber, P., Menzi, H., 2006. Nitrogen losses from intensive livestock farming systems in Southeast Asia: A review of current trends and mitigation options. Greenh. Gases Anim. Agric. Update Proc. 2nd Int. Conf. Greenh. Gases Anim. Agric. Held Zurich Switz. 20 24 Sept. 2005 1293, 253–261. doi:10.1016/j.ics.2006.01.028

IAEA, F., 2008. Guidelines for Sustainable Manure Management in Asian Livestock Production Systems. Jt. FAOIAEA Div. Nucl. Tech. Food Agric. Int. At. Energy Agency IAEA VIENNA.

MacLeod, M., Gerber, P., Mottet, A., Tempio, G., Falcucci, A., Opio, C., Vellinga, T., Henderson, B., Steinfeld, H., 2013. Greenhouse gas emissions from pig and chicken supply chains - A global life cycle assessment. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy.

Ma, L., Ma, W., Velthof, G., Wang, F., Qin, W., Zhang, F., Oenema, O., 2010. Modeling nutrient flows in the food chain of China. J. Environ. Qual. 39, 1279–1289.

Schaffner, M., Bader, H.-P., Scheidegger, R., 2009. Modeling the contribution of pig farming to pollution of the Thachin River. Clean Technol. Environ. Policy 12, 407–425. doi:10.1007/s10098-009-0255-y

Seré, C., Steinfeld, H., 1996. World livestock production systems. Current status, issues and trends., Animal Production and Health. Food and Agriculture Organization of the United Nations, Rome.

Strokal, M., Ma, L., Bai, Z., Luan, S., Kroeze, C., Oenema, O., Velthof, G., Zhang, F., 2016. Alarming nutrient pollution of Chinese rivers as a result of agricultural transitions. Environ. Res. Lett. 11, 024014.

Uwizeye, A., Gerber, P.J., Schulte, R.P.O., de Boer, I.J.M., 2016. A comprehensive framework to assess the sustainability of nutrient use in global livestock supply chains. J. Clean. Prod. doi:10.1016/j.jclepro.2016.03.108

Yamaji, K., Ohara, T., Akimoto, H., 2004. Regional-specific emission inventory for NH3, N2O, and CH4 via animal farming in South, Southeast, and East Asia. 8th Int. Conf. Atmospheric Sci. Appl. Ions Air Qual. ASAAQ 38, 7111–7121. doi:10.1016/j.atmosenv.2004.06.045