Comparing nitrogen budgets in shrimp and rice-shrimp ponds in Vietnam

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Abstract
Saline water intrusion has become a severe issue facing the Mekong region of Vietnam, especially in coastal areas. This issue has resulted in farmers diversifying from growing exclusively rice to adopting integrated rice-shrimp culture systems. However, the nitrogen (N) cycling and N use efficiency of these systems remains poorly understood. To address this knowledge gap, we examined nutrient budgets across 12 farms adopting integrated rice-shrimp ponds or intensive grow-out ponds over a one year period. The main N input (95%) in the rice-shrimp ponds came from inlet water, while only 2% of N in outlet water was due to shrimp farming. Shrimp survival rates in mixed rice-shrimp systems were low over the year (4.3 - 5.6%). In contrast, intensive grow-out ponds growing only shrimp on the same farms had significantly higher survival rates (66.4 - 82.3%) when the crop survived through to harvest. In these ponds, formulated feed was the highest input (65% N) with 44% N being in shrimp harvest. These results show that N in the rice-shrimp ponds was used less efficiently than in grow-out ponds and that mechanisms to improve survival rates and production are urgently needed.

Key Words: budget, grow-out pond, input, nitrogen, output, rice-shrimp pond.

Introduction
Shrimp farming is one of the most valuable sectors of the Vietnamese economy and approximately 76% of Vietnam's shrimp production occurs in the Mekong Delta (Tho et al., 2013). Even though shrimp farming has been undertaken in intensive systems with high stocking densities, recent years have seen the expansion of new integrated rice-shrimp production farms. The rice-shrimp farming systems involve growing rice (and in some cases combined with shrimp) in the wet season, while only shrimp are farmed during the dry season. The adoption of this practice has substantially increased in Vietnam over the last years, growing from around 40,000 ha in 2000 (Preston and Clayton, 2003) to 160,000 ha in 2015 (VNN, 2015). Despite this, there have been few studies of the long term sustainability of these systems.

One measure of sustainability of rice-shrimp systems is associated with nutrient processes, including identifying the key inputs and outputs of N. However, there has been no research focussed on this aspect with previous studies only focussed on nutrient budgets in intensive aquaculture ponds, where formulated feed is used. In this study, we compare N budgets in rice-shrimp ponds and adjacent intensively stocked grow-out ponds to identify the dominant inputs and outputs and the relative effectiveness of nutrient utilization by shrimp in the two systems.

Methods
The study investigated 12 farms along a canal in Ca Mau province, Vietnam, over the period of Feb 2014 to Jan 2015. Of these, six farms employed exclusively the rice-shrimp cultivation method, consisting of a platform with shallow water (typically 0.1 - 0.4 m deep, 80% of the area) and a surrounding ditch (typically 1.1 - 1.5 m deep, 20% of the area), known as the control group. The remaining six farms adopted a combination of the rice-shrimp system and adjacent newly constructed grow-out ponds with shrimp grown in semi-intensive or intensive conditions, known as the trial group. Grow-out ponds were stocked once early in the dry season and once early in the wet season with *Penaeus monodon* or *Penaeus vannamei* at a density of 30 post-larvae.m^{-2}. Rice-shrimp ponds were stocked every 2-3 months during the one-year cycle with *P. monodon* at a mean density of 2 post-larvae.m^{-2}. Mud crabs (*Scylla* spp.) were also present in the rice-shrimp ponds at an estimated density of 0.5 crab.m^{-2}. Formulated feed was added to grow-out ponds while shrimp in rice-shrimp ponds consumed only natural food present in ponds.

In rice-shrimp ponds, partial harvest events were carried out on average 6-7 times a year using trap nets. Ten randomly selected fresh shrimps were weighed at each harvest to estimate total live biomass and mean fresh body weight (MWT). Occasionally, mud crabs were also harvested. Grow-out ponds were drained and all shrimp were harvested one time at the end of the culture period. The feed conversion ratio (FCR) was calculated for the grow-out ponds as well as survival rate and total shrimp biomass. FCR was determined as total weight of dry feed given divided by the total weight gain. Survival rate was defined as number of shrimp harvested divided by the initial number of shrimp stocked in each pond. Total shrimp biomass was calculated as final total shrimp (wet weight) per crop.

Physical-chemical parameters, including temperature, salinity and oxygen, were measured weekly using calibrated loggers, whereas water samples for N analysis were collected monthly. Samples were taken with a bucket from the inlet water, each ditch in the rice-shrimp ponds and each grow-out pond. Samples for total N (TN) analysis were placed in vials, while samples for total dissolved N (TDN), ammonium ($N\text{-}NH_4^+$), nitrate ($N\text{-}NO_3^-$) and nitrite ($N\text{-}NO_2^-$) analysis were filtered through 0.45 µm membranes and kept cold until analysed. $N\text{-}NH_4^+$ was analysed using the phenate method; $N\text{-}NO_2^-$ and $N\text{-}NO_3^-$ using the cadmium reduction and TN and TDN using the persulfate method (APHA, 2005). In the grow-out ponds, sediment samples were collected by taking different cores (up to 15 cm depth) from each pond and mixed in a composite sample for analysis. All sediment samples were air-dried, pulverized to pass a 0.25 mm mesh and analysed for TN. TN content for shrimp feed, fertilizer and carcasses of harvested shrimps was also analysed using the same method as for sediment. Samples were prepared by freeze-drying and pulverizing in order to pass samples through a 0.85 mm mesh before being analysed.

Water exchange for all ponds was quantified. TN inputs and outputs in the culture system were based on inputs from water, fertilizer and feed, and outputs included harvested shrimp, discharge water and sediment. Inputs and outputs were calculated as follows:

N input in water = N concentration in inlet water × total amount of water supplied.

N input in fertilizer = N concentration in fertilizer × total amount of fertilizer supplied.

N input in feed = N concentration in feed × total amount of feed supplied.

N input in shrimp = N concentration in shrimp stocking × total shrimp stocking.

N output in water = N concentration in outlet water × total amount of water released.

N output in shrimp = N concentration in shrimp harvesting × total shrimp biomass.

N output in sediment = N concentration in the sediment × total mass.

N output in crab = N concentration in crab harvesting × total crab biomass.

Results

Mean shrimp survival rates were extremely low (4.3 - 5.6%) across all the 12 rice-shrimp ponds (Table 1).

Table 1. Production (mean ± SD) and related data for the 12 rice-shrimp ponds (trial group and control group)

Group	Pond area (m^2)	Survival (%)	Culture period (months)	Shrimp yield ($kg.ha^{-1}$)	Crab yield ($kg.ha^{-1}$)
Control	20,417 ± 4,224	4.3 ± 1.6	12	103.2 ± 40.3	17.4 ± 22.5
Trial	24,500 ± 9,439	5.6 ± 2.7	12	113.2 ± 37.5	38.4 ±17.3

For the intensive grow-out ponds, the survival rates of the shrimp varied substantially, with a mean of 75% for those ponds where a harvest was achieved. The shrimp production ranged from 0 to 5,358 kg ha^{-1} with an average of 4,408 kg ha^{-1} (Table 2). FCR ranged from 1.2 to 1.6 with a mean of 1.4

Table 2. Production data (mean ± SD) of grow-out ponds (trial group)

Shrimp	Pond area (m^2)	Survival (%)	Culture period (days)	Harvest size ($shrimp.kg^{-1}$)	Shrimp yield ($kg.ha^{-1}$)	FCR
P. monodon	2,462 ± 749	82.3 ± 14.1	84 ± 20	66 ± 23	5,358 ± 2,325	1.2 ± 0.1
P. vannamei	2,417 ± 984	66.4 ± 14.2	141 ± 23	49 ± 17	2,069 ± 708	1.6 ± 0.3

No statistically significant differences were found in terms of TN concentrations in the water column of integrated rice-shrimp ponds between the control and trial group, ranging from 3.03 to 3.14 mg N L^{-1} in the dry season crop, and 0.64 to 1.16 mg N L^{-1} in the wet season crop. TDN concentrations in rice-shrimp ponds fluctuated throughout the year with no obvious changes between the wet and dry season crop. In contrast, the grow-out ponds had much higher discharges of N at the end of the dry season crop (June) and wet season crop (January), with significant increases in ammonium and nitrate levels (Fig. 1)

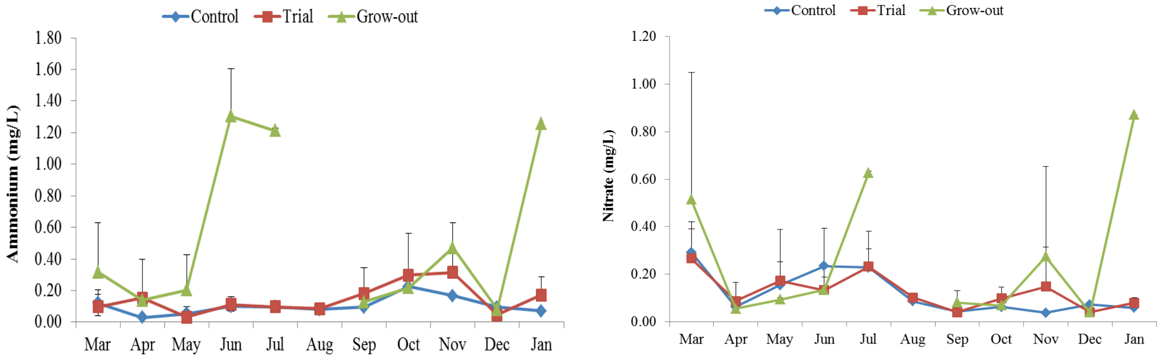

Figure 1. Ammonium and nitrate concentrations in the water column in rice-shrimp and grow-out ponds

The N budget was calculated for all ponds in the study. For the grow-out ponds, feed was the major input of N (65%), followed by intake water (23%) (Fig. 2A). Shrimp biomass was the dominant output of N (44%) (Fig. 2B). A major portion of the N inputs was also deposited as the sediment on the floor of the ponds as well as discharged over the season in the discharge water (21% and 19%, respectively, of total N retention in the culture system). Unaccounted N outputs amounted to roughly 16% (Fig. 2B).

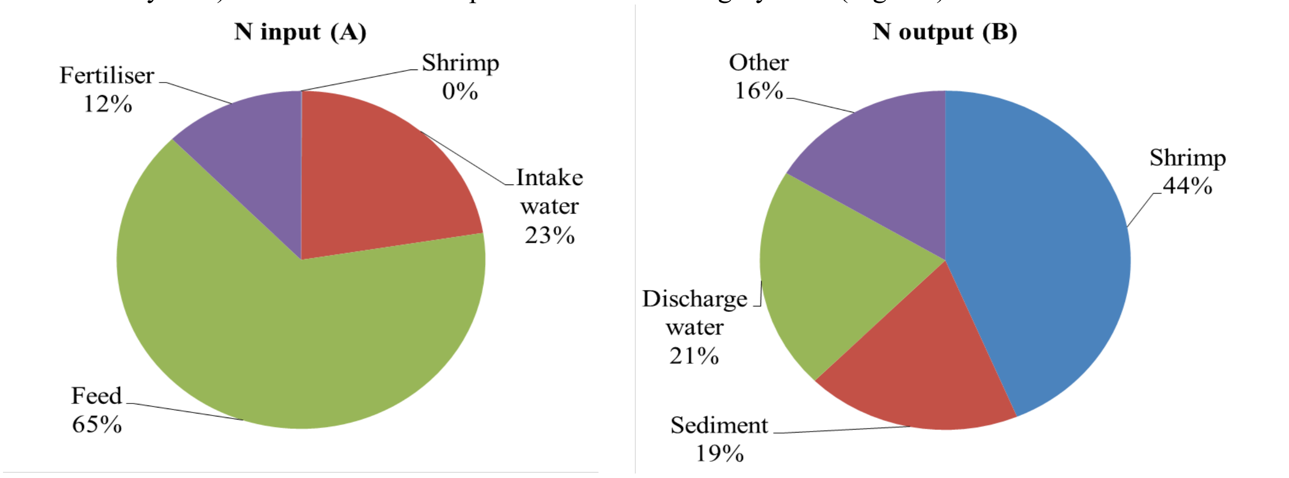

Figure 2. Percentage N input (A) and output (B) in grow-out ponds

In the rice-shrimp ponds, water intake was the main N input (95%) and fertiliser addition only accounted for 5% (Fig. 3A). Shrimp harvest was only around 5-6% of the total stocking; hence shrimp only occupied 2% of total N output (Fig. 3B). 50% of N output remained unaccounted, and is likely to have been associated with sediment and/or incorporated into benthic algal biomass in the platforms.

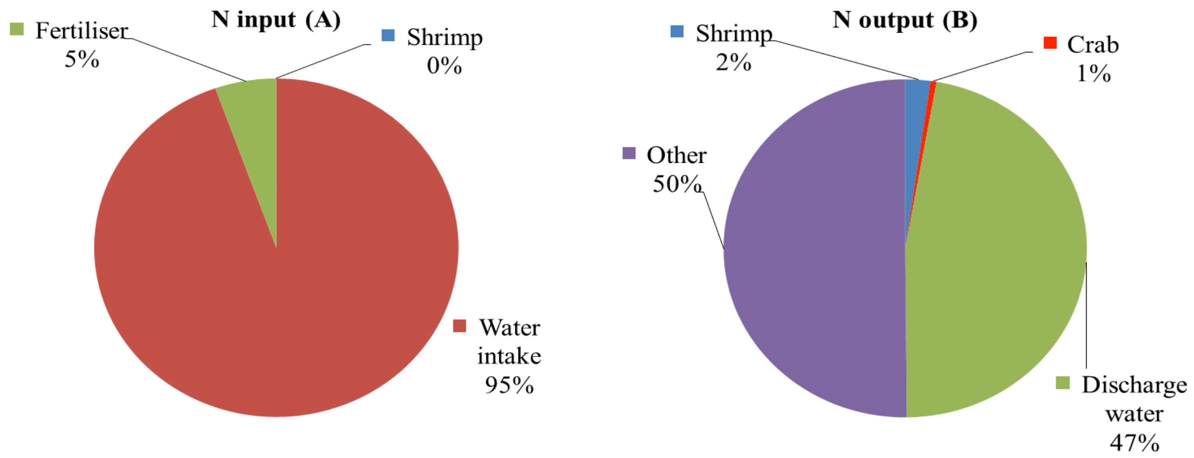

Figure 3. Percentage N input (A) and output (B) in rice-shrimp ponds

Discussion

The N input in grow-out ponds was 243 kg N ha^{-1}, where feed contributing the most (65% - 159 kg N ha^{-1}) to sustain an average stocking density of 30 post-larvae.m^{-2}. Similar results were observed in Chinese shrimp farms studied by Xia et al. (2004), where N input in shrimp ponds was 193 kg N ha^{-1} with a stocking density of 50 post-larvae.m^{-2}. However, the N input due to feed in our study was much lower than the one reported by Sahu et al. (2013) on intensive ponds (95% - 44 to 104 kg N $crop^{-1}$). These N budgets indicate that grow-out ponds are relatively efficient in transferring N inputs to shrimp harvest (Alongi et al., 2000).

In contrast, rice-shrimp ponds were less efficient, with low shrimp survival and relatively low N recovery into shrimp. Compared to N concentrations in water outlets from grow-out ponds, N concentrations in water discharged from rice-shrimp ponds were substantially lower. It may be suggested that as the rice-shrimp culture system did not get any formulated feed, this would have contributed to reducing the N concentration in the water. Although the rice-shrimp model can reduce the N loss through pond effluents and thus minimize the environment impacts of shrimp culture (Thakur et al., 2003), the low shrimp survival means that this system is still inefficient.

It is also possible that some unaccounted N output in the rice-shrimp system was sequestered by the sediment through accumulation of organic sludge. Hence, sediment accumulation was likely to be responsible for a significant percentage of the N output, which could not be accurately accounted for in the present study. N in benthic algae could also not be measured accurately. The management of benthic algae in rice-shrimp ponds could be important because this is the natural source of nutrients for shrimp. At times, large amounts of nutrients are stored in macrophytes (aquatic plants) and benthic microalgae on the platform, but this biomass was found to vary considerably over time and between farms. It is unclear what drives this variability but the changes in salinity and temperature may affect algal biomass production.

Conclusion

In grow-out ponds, feed was the major input of N (65%), followed by intake water (23%). For rice-shrimp ponds, water intake was the main input (95%), and shrimp only accounted for 2% of N output because of low shrimp survival (4.3 - 5.6%). The nutrient budget indicates that good production and low FCRs can be achieved from well managed grow-out ponds, whereas rice-shrimp ponds appear inefficient systems for transfer of N with low shrimp survival. Therefore, solutions for the sustainability of the rice-shrimp model are necessary to improve shrimp survival rates and productivity.

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