J. Indian Soc. Coastal Agric. Res. 38(2): 125-131 (2020)

Reducing the Carbon Footprint from Pond Aquaculture in a Changing World

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Received: 02.04.2020 Accepted: 10.09.2020

The contribution of aquaculture to the total greenhouse gas (GHG) emission from agriculture is small. However, it is a major concern as aquaculture is one of the fastest growing agricultural activities. Life cycle analysis (LCA) indicates that formulated feed is the major contributor to GHG emission from aquaculture. Depending on the boundaries set for the LCA, the contribution from feed to GHG emission varies between 24 and 93%. Therefore, insight in the mechanisms of GHG emission is important. Carbon dioxide (CO_2) is the major contributor to global warming, but other gases, of which nitrous oxide (N_2O) and methane (CH_4) are the most important gases, are responsible for close to 30% of global warming. All water bodies release GHG, and the difference in emission between a natural water body and an aquaculture pond should be considered. Generating more in-depth insight in GHG emissions from aquaculture production systems in function of farm system design and operation is needed to develop strategies to reduce emissions from aquaculture farms. Ecological intensification by growing fish/shrimp within the carrying capacity of the pond, or using renewable energy such as solar power for farm operation, and using more efficient equipment, can help to reduce GHG emissions. The nutritious pond concept is providing nutrient inputs to ponds, aiming for a metabolic waste/faeces composition resulting from feeding that is easily degradable by microbiota and hence stimulates the natural food web of the pond. A dual-purpose feed is formulated that feed the fish directly and indirectly, as feed and natural food, respectively. The concept aims to reach the maximum production potential within the carrying capacity of the pond and might even be able to increase the carrying capacity through the efficient biogeochemical cycling of nutrients. The fact that in semi-intensive tilapia ponds fed nutritious pond feed, the protein contained in harvested fish was more than 70% of the protein fed, shows the nutrient utilization efficiency is high. How nutritious pond farming will influence GHG emissions from ponds needs further investigation.

(***Key words:*** *CO_2 emission, Ecological intensification, Greenhouse gas emission, Methane emission, Nutritious pond concept)*

Fish play an important role in meeting the current and future food demands within the global food system. Fish, from aquaculture and fisheries combined, provide at least 15% of the animal protein demand of 4.3 billion people (Lynch, 2017) and contributes 3.11% of global GDP (FAO, 2018). Fish demand increases with population growth. Supply of fish from capture fishery has been static for the last decades, meaning that current increases in fish supplies are coming from aquaculture. Consumption of fish from aquaculture as part of global supply grew from 6% to 53% in the last 50 years. Aquaculture is the fastest growing food sector and in 2016 had a total annual production of 80 million metric tons, valuing ~180 billion USD (FAO, 2018).

This rapid growth of aquaculture significantly improved food and nutrition security, economic growth and employment creation. However, this growth is also responsible for several environmental impacts. Most of the environmental impacts are local or regional and are very much context specific. Environmental impacts include chemical pollution, depletion or enrichment of nutrients, habitat loss, disease, introduction of exotic species, inefficient energy and biotic resource use, etc. (Henriksson and Elletier, 2013). In contrast to most environmental impacts from aquaculture, Greenhouse gas (GHG) emission is a global phenomenon, common across all aquaculture production systems. Carbon dioxide, methane and nitrous oxide are the three major

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gas referred to as GHG. The carbon footprint is one of the popular indicators used to evaluate the total GHG released during the complete life cycle of certain products and services, from the gathering of raw materials to manufacturing, assembly, and transportation, as well as use, disposal and waste treatment (Williams, 2009).

GHG emission continues to rise and is a major threat to sustainability. According to IPCC (2014), emission from agriculture is 4th largest contributor to GHG emissions behind electricity and heat production, industry and transportation, responsible for 14% of the total emission. The contribution of aquaculture to the total emission from agriculture is still little but is a major concern as aquaculture is one of the fastest growing agricultural based activities. Besides carbon dioxide, methane emission from water bodies is naturally occurring, therefore expansion of aquaculture means expansion of methane emission. Ongoing intensification concurring with increased reliance on formulated feed input will further increase emissions of carbon dioxide and nitrous oxide as well. According to Paris agreement (COP 21) all signed parties agreed to reduce GHG emissions by 2030. That means the production needs to be more efficient so that we can achieve the expected doubling of yield without increasing the carbon footprint, which is very challenging.

This review aims to present a general overview on how GHG emission is measured, what are the main types of GHG emission from aquaculture, and where to reduce GHG emission sufficiently to create space to double aquaculture production by 2050. The second part is to theoretically analyse the potential of the nutritious pond concept in addressing the emission of the three major GHG gas.

How is GHG emission measured?

The most popular way of measuring GHG emission is by life cycle assessment (LCA) of a particular commodity where emissions throughout the value chain are considered. An example of LCA on a salmon farm (Pelletier *et al*., 2009) indicated that 93% of GHG emission is from feed and feed related activities such as feed ingredients from the crop, fisheries (fishmeal), livestock (meat and bone meal), feed manufacturing and transport. Here, more than 85% of the emission is coming from feed ingredients, with fishmeal alone responsible for 52%. However, in this analysis, post-harvest losses were not included. Another LCA on an ecological shrimp farm in China (Chang *et al*., 2017) that included post-harvest and waste treatment had electricity (29%), feed (24%), indirect raw materials which are mainly used for pond preparation and water quality maintenance (22%), waste treatment (11%) and transport and refrigerant (11%) as main contributors to GHG emission. If we compare the above two assessment outcomes, we can conclude that framing the boundaries of the LCA, and species and farming system choice result in large differences in LCA output.

There is also variation within the same species and farming system. For example, yield from semi-intensive black tiger shrimp farm can range from 3000 to 7000 kg ha^{-1} $year^{-1}$ (Ahmed, 2013; Faruque *et al*., 2017). With changing the yield the intensity of input use changes causing differences in GHG emission related to amount and types of input. On the other hand, some emissions from water bodies are natural and do not change much with the culture intensity. However, this context specific changes are difficult to capture in LCA. Again for feed use, there are feeds with 25-40% protein content, with large variation in ingredients used that provide protein. If the fish meal is a major part of the protein, the emission will be higher compared to plant protein (Henriksson *et al*., 2014). If the ingredients are locally sourced or imported, also affects the total carbon footprint of the final product. Shrimp, which is mainly exported, has a large footprint from the processing (freezing) and shipment while carps which are often locally consumed do have a much smaller portion of emission during post-harvest handling.

One of the major alarming GHG components from aquaculture is N_2O (nitrous oxide) which can vary a lot based on the amount of protein and their utilization. An efficient nitrogen cycle will lead to less emission and an increase in temperature will reduce N_2O emission from aquaculture (Paudel *et al*., 2015). So, the climate also influences emission. CH_4 (methane) emission is naturally occurring from waterbodies. Conversion of wetlands to aquaculture ponds often requires deepening of the pond. CH_4 emission is higher in shallow water bodies compared to deeper aquaculture ponds (Peacock *et al*., 2019). The trade-off in emission between a natural water body and an aquaculture operation should also be considered in LCA. The values of emission from different inputs and management practices calculated in LCA are also based on some assumption which can largely vary (Henriksson *et al*., 2018). Due to these limitations, some scientists prefer the estimation of emission directly from the farming system (Vasanth *et al*., 2016).

Estimation of direct GHG emission cannot capture the total emission from the complete product development phase but presents a more accurate value coming directly from the farming system. Such a direct measurement on GHG emission from white leg shrimp (*Litopenaeus vannamei*) ponds in India reports 4.56 kg CO_2e kg^{-1} shrimp yield (Vasanth *et al*., 2016) which is 35% less than the reported (6.94 kg CO_2e kg^{-1}) emission for the same species using LCA (Chang *et al*., 2017). There are few studies which have measured directly GHG emission as well as used LCA to do a meta-analysis on comparison of the methods. We can conclude that direct emission from aquaculture ponds is a fraction of the emission from the product value chain. Moreover, direct emission measured from an open water aquaculture system, such as cage culture, is not a real representation as well.

How can we reduce GHG emission?

In general, five major segments of GHG emission are electricity, feed, indirect material cost, waste treatment and post-harvest processing, including transport. Ecological intensification by growing fish/shrimp within the carrying capacity of the pond, or using renewable energy such as solar power for farm operation, and using more efficient equipment, can minimize reduce energy use. Also for many species, aeration or water pumping are not required. Hence, reducing GHG emissions by adapting farming systems design can be explored.

Emission from fish transportation and refrigeration can also be minimized by diversified siting of processing and distribution plants nearer to demand areas and improving efficiency. Of course, relocation of production for all species is not feasible. Eleven per cent of globally traded fish are exported to Africa (FAO online) while this continent has plenty of water resources to grow fish. Instead of inter-continental trade, regional trade can minimize GHG emission.

However, the most challenging part is addressing the emission from feed, indirect raw materials and waste treatment. With the current growth rate and the projected doubling requirement, feed use will inevitably increase near to double, leading to increase in the waste which is mainly driven by the feed and also with increased feed and waste, to keep the water quality balanced more medicine, chemicals or equipment will be required (Fenchel *et al*., 2012). Emission from feed depends mainly on two factors - the types of ingredient used and utilization efficiency of the feed. For example, fishmeal has more GHG emission compared to rice bran. But, fishmeal provides protein in the diet while rice bran is mainly for energy and comes as a co-product. If we add protein from plant based sources such as soybean meal, the emission is comparable. However, this change in ingredient composition can influence the utilization efficiency of the feed and might raise the overall emission. Increased inclusion of plant based ingredients in fish feed is a growing trend. Often the inclusion of plant based ingredients leads to increased waste production (Tran-Tu *et al*., 2018), meaning that more emission will come from the waste management section. The core motto for reducing emission is "Reduce, Reuse, and Recycle". So we have to grow more with less by increasing input use efficiency. In addition, reuse and recycle resources within the production system or in the linked production system (Ahmed and Glaser, 2016). One example can be growing crops with wastewater or using the bottom sludge as fertilizer for crops.

What is nutritious pond concept (NPC)?

The nutritious pond concept is providing nutrient inputs to ponds, aiming for a metabolic waste/faeces composition resulting from feeding that is easily degradable by microbiota and hence stimulates the natural food web of the pond. The enhancement effect on the food web includes algae, heterotrophic and chemoautotrophic microbiota, zooplankton and benthos in the water column and sediment. A concept of dual purpose feed was developed, which feeds the fish directly and indirectly, as feed and natural food, respectively (Fig. 1). It follows the core motto of GHG emission reduction - "Reduce, Reuse, and Recycle". Because of the enhanced contribution of natural food we can grow more with less. The uneaten feed and feed driven waste is largely reused/recycled within the pond for enhancing the natural food. It aims to reach the maximum production potential within the carrying capacity of the pond and might even be able to increase the carrying capacity by efficiently functioning the biogeochemical cycle in the pond.

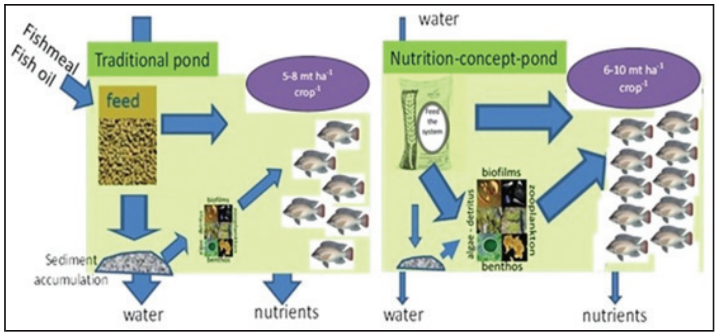

Fig. 1. *Conceptual drawing visualizing the difference between a "traditional pond" to a "nutritious pond"*

In traditional ponds feed targets the farm animal, not considering fertilizer effects. In nutritious ponds, feed is applied to nourish the whole system by feeding the fish directly and indirectly through natural foods produced based on nutrients resulting from feed application. Natural foods include phytoplankton, benthic organisms, detritus, zooplankton, biofilms (bottom and periphyton). In traditional ponds a large fraction of nutrients accumulates in the sediment, while in the nutritious pond more nutrients pass through the natural food web, reducing nutrient accumulation in the sediment.

How nutritious pond concept helps reducing carbon footprint?

N_2O emission

N_2O emission takes place from incomplete nitrification and denitrification. The total emission of N_2O depends on nitrogen (N) input mainly via feed and fertilizer and output in the fish biomass. The more N is included the higher N_2O emission (Hu *et al*., 2012). Therefore, a reduction in the feed N input will reduce N_2O emission. An NPC-feed contains less protein compared to conventional diets (Kabir *et al*., 2019a) and thus less N_2O emission assuming that the production systems are the same, except the feed.

In addition to total N input, the efficiency of N use in the system also partly regulates the N_2O emission from aquaculture. In the conventional diets, 25% of feed N is converted to fish biomass and subsequently, rest passes through the aquatic nitrogen cycle and 20% becomes N_2O and N_2 (Hu *et al*., 2012) where the part of N_2O is very little. In semi-intensive tilapia ponds using NPC-feed, the N retention in fish biomass was above 70% (Kabir *et al*., 2019b). Therefore, application of NPC-feed in pond aquaculture can reduce 2.85 folds of direct N_2O emission from the farming system.

CH_4 emission

Aquaculture ponds are potentially large sources of atmospheric methane (CH_4) that can exacerbate climate change. A thorough understanding of various CH_4 biogeochemical processes occurring in the ponds is essential for the prediction and management of CH_4 emissions arising from aquaculture. Studies on shrimp ponds in Min River Estuary and Jiulong River Estuary in China indicated that CH_4 concentration is higher in bottom water compared to middle and surface water and the concentration gradually increases with the progress of the culture cycle (Yang *et al*., 2019). CH_4 fluxes across the sediment-water interface and CH_4 oxidation rate in the overlying water significantly varied between the ponds from two different deltas indicating that the soil properties and overlying water influences CH_4 dynamics in aquaculture ponds. Similarly, the enhancement of the food web in pond aquaculture with NPC-feed also is partly regulated by the soil and water properties. However, the methanotrophic bacteria, enhanced by the application of NPC-feed in the pond aquaculture breaks down CH_4 via type I and type II methanotrophs (Fig. 4) and produces microbial biomass (Hanson and Hanson, 1996), while reducing CH_4 emission.

However, to what extent the NPC-feed enhances the methanotrophic bacteria and as a consequence at what percentage of CH_4 emission is reduced from the aquaculture ponds has not been quantified. Specific research on this agenda can generate interesting information on carbon footprint management from aquaculture as by quantity CH_4 is the 2nd largest GHG emission from aquaculture.

CO_2 emission

A cumulative respiratory CO_2 emission from all living biota from aquaculture is responsible for direct

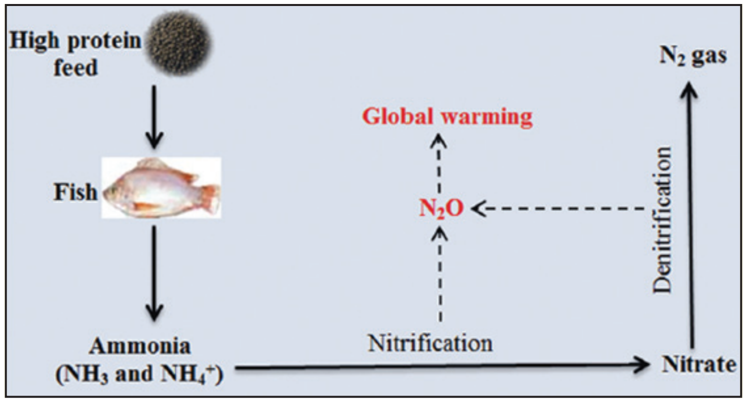

Fig. 2. *Conceptual diagram on N_2O emission from feed N. Copied from (Hu et al., 2012)*

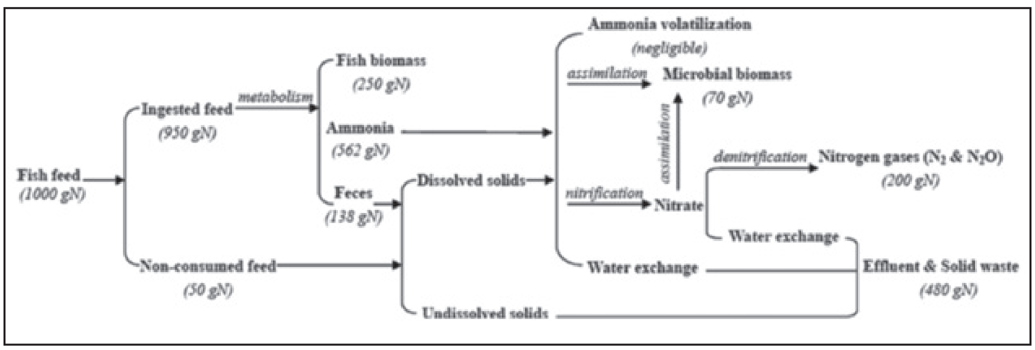

Fig. 3. *Principal transformation process of nitrogen in aquaculture system. Assuming a nitrogen input of 1000 g N, and the nitrogen transformation in each pathway is based on the statistical analysis of literature published. (Source: Hu et al., 2012)*

emission of CO_2 from the farming system. As many of the biota ends up into fish biomass and productivity increases per unit of feed input it is assumed that CO_2 emission per unit of fish/shrimp produced is less compared to the conventional approach. However, there is no clear pathway to justify this claim. Direct GHG emission measurement from the farms under NPC and conventional approach can provide insight on it.

Waste management

Application of NPC allows reuse and recycling of nutrients in a productive way within the system. Kabir *et al*. (2019b) found that the amount of nutrients present at the end of the production cycle is equal or less than the amount present at the start. As a major portion of waste is recycled and reused within the pond during the culture period, the likelihood of GHG emission from waste treatment is less under the nutritious pond concept compared to a conventional approach. However, this has not been quantified yet.

Use of aqua-chemicals

Application of NPC keeps a good balance between nutrient application, uptake and waste generation. As a result, the pond environment remains healthy. Comparisons on aqua-chemicals used in conventional tilapia or shrimp farms are much less compared to the NPC demonstration for tilapia by Kabir *et al*. (2019b). However, the difference in GHG emission due to lesser application of aqua-chemicals has not yet been quantified.

Application of the nutritious pond concept has great potential to reduce direct GHG emission from (farming systems of) pond aquaculture. In addition, in feed except for the crude protein ingredients, others are often co-products from agriculture and cause less GHG emission. In the NPC-feed the inclusion of protein ingredients are significantly less and co-products are more. Assessment of product lifecycle of NPC is therefore also likely to reduce GHG emission. However, all the arguments

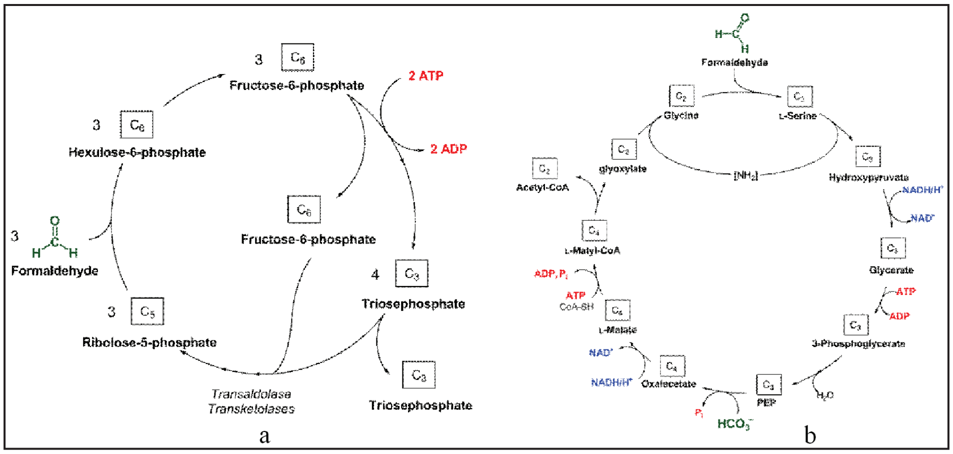

Fig. 4. *Methane oxidation by methanotrophs: "a" is ribulose monophosphate (RuMP) pathway in type I methanotrophs and "b" is Serine pathway in type II methanotrophs. The figures are copied from (Hanson and Hanson, 1996)*

about the potential of NPC in reducing carbon footprint are presented based on a theoretical framework and very little evidence is yet generated to support the claims. Therefore, research on the quantification of GHG emission from NPC by both direct emission estimation and LCA is required.

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