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Reuse of fish pond sediments as fertilizer for fodder grass production in Bangladesh: Potential for sustainable intensification and improved nutrition

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ABSTRACT

Intensive aquaculture systems (e.g. pangasius farming) make important contributions to food security in developing countries, including Bangladesh, but are associated with a variety of negative environmental impacts, including the discharge of nutrient rich sediments into local ecosystems. The present study consists of laboratory based analysis of the nutrient content of pangasius pond sediments (PPS), a trial of the efficacy of reuse of PPS as fertilizer to produce para grass as a green fodder for dairy cattle, and a comparative assessment of the economic viability of para grass production in rice fields using PPS to support small-scale dairy farming operations, thereby removing a major constraint to the growth of commercial dairy production in Bangladesh. PPS had significantly higher levels of organic carbon, nitrogen, phosphorous, potassium and sulfur than rice plot soil, and was a highly effective fertilizer for para grass cultivation. Production of green fodder for dairy cows using PPS yielded a higher rate of return than rice production. The indirect integration of aquaculture with agriculture through the reuse of PPS as fertilizer for green fodder production has significant potential to contribute to sustainable intensification and nutrition security goals, by improving the efficiency of nutrient use in aquaculture, reducing local environmental impacts associated with sediment disposal, and increasing the production of micronutrient rich milk.

1. Introduction

The challenge of meeting rapidly growing demand for food from a larger and more affluent global population in ways that are environmentally sustainable, whilst ensuring that the world's poorest people are no longer hungry, demands sustainable intensification; simply defined as producing more food from the same area of land while reducing the environmental impacts (Godfray et al., 2010). This paper describes results of on-farm trials in Bangladesh, designed in response to these imperatives, to recycle nutrient wastes from intensive pangasius aquaculture for the production of para grass, a fodder used in small-scale dairy farming.

Bangladesh has achieved near self-sufficiency in rice production and made significant progress against a variety of other development indicators despite being one of the poorest and most densely populated countries in the world. However, a substantial proportion of the population continues to experience moderate or severe food insecurity and malnutrition (HKI, 2014). Undernutrition is symptomatic of inadequate micronutrient intakes, and is associated with a range of negative health outcomes, including anemia, poor growth, rickets, impaired cognitive performance, blindness and neuromuscular deficits (Murphy and Alleny, 2003). Animal source foods provide a variety of micronutrients that are difficult to obtain in adequate quantities from plant source foods alone, and relatively small amounts of these foods added to a vegetarian diet can substantially increase nutrient adequacy (Murphy and Alleny, 2003). Milk is the most complete of all foods, containing nearly all the constituents of nutritional importance to humans.

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Table 1
National average daily per capita intake of total food and dairy products (grams) (source: derived by authors from Bangladesh Bureau of Statistics Household Income and Expenditure Survey datasets for 2000, 2005 and 2010).

Consumption	Year		
	2000	2005	2010
Total foods	893.1	947.7	1000.0
Dairy products	29.7	32.4	33.7

The dairy sector in Bangladesh is limited in scale by lack of year-round feed supplies (Uddin et al., 2011), and the majority of dairy farmers identify limited availability of good quality fodder as their major constraint (Akbar et al., 2000). As a result, the gap between milk supply and demand in Bangladesh is large, and average milk consumption per capita is much lower than other South Asian countries such as India and Pakistan (FAO, 2010). Average daily per capita intakes of dairy products barely moved over the period 2000–2010, despite major improvements in total food consumption (Table 1), and Bangladesh spent US$ 93.4 million in the fiscal year 2012–2013 to import 20,000 MT of powdered milk (Hamid and Hossain, 2014).

Aquaculture is the most rapidly expanding food sector globally in relative terms, growing at a rate of 8.8% per year since 1980, and food–fish production from aquaculture more than doubled from 32.4 million MT to 66.6 million MT over the decade 2000–2012 (FAO, 2014). Global demand for fish is set to increase rapidly in future as developing country incomes and populations climb, and production is projected to increase a further 35% by 2022, to reach 85 million MT (OECD-FAO, 2013). However, although broadly positive in terms of its overall impacts on food and nutrition security (Belton and Thilsted, 2014), aquaculture's dramatic growth trajectory has often proven controversial, particularly with respect to environmental impacts.

Bangladesh is the world's fifth largest aquaculture producer (FAO, 2014). Production of farmed fish increased 2.4 times from 0.79 million MT in 2001–2002 to 1.9 million MT in 2012–2013 (DoF, 2014). Pangasius catfish (*Pangasianodon hypophthalmus*) accounted for about 15% of total recorded aquaculture production in 2012–2013 (DoF, 2014). Pangasius farming in Bangladesh is characterised by high stocking densities, intensive supply of pelleted feeds with an average feed conversion ratio (FCR)[1] of 2.00, and high yields, averaging around 40 MT ha^{-1} (Ali et al., 2013). Intensive feeding of pangasius results in the accumulation of large quantities of sediments on the pond bottom (Anka et al., 2013), containing high levels nitrogen, phosphorous and organic carbon (Nhan et al., 2006). In pangasius farming, 70–80% of such nutrients are deposited in pond sediments (Rahman et al., 2004; Anh et al., 2010; Boyd et al., 2011), with the reminder removed in the form of harvested fish (Edwards, 1993).

Cumulative build-up of nutrients results in deteriorating water quality, which can trigger stress and diseases in cultured fish, reducing farm productivity (Anka et al., 2013). Regular removal of pond sediments is therefore an optimal management practice, but manual excavation after draining and drying ponds is labour intensive (Haque et al., 2013). Pumping out liquid pond sediments into drainage canals is a more cost effective alternative sometimes employed in Bangladesh, but this unplanned discharge is known to cause problems with local waterlogging, multiplication of disease vectors, eutrophication of receiving rice fields and waterbodies, blocked access, and conflicts with neighbouring farms (Haque, 2009; Anka et al., 2013). In Vietnam, discharge of wastewater and pond sludge from intensive pangasius farms is reported to result in high levels of biochemical oxygen demand and elevated concentrations of total suspended solids in receiving waters, as well as acting a point source of nutrients which can cause local eutrophication (Anh et al., 2010). Zhang et al. (2015) found that nutrient discharges from freshwater aquaculture into Chinese aquatic ecosystems in 2010 included 860 Gg N and 151 Gg P, and recommend the recycling of nutrients in water and sediments by integrated agriculture–aquaculture systems and the adoption of nutrient use efficiency as indicators at farm or regional level for the sustainable development of aquaculture.

Concerns about the environmental impacts of intensive aquaculture have resulted in the proliferation of private sustainability standards (Bush et al., 2013). The negative effects of farm discharge on the receiving aquatic environment are among the main environmental impacts that these standards seek to regulate (Jonell et al., 2013; Boyd et al., 2005). However, compliance with sustainability standards often requires the construction of settlement ponds to prevent the discharge of nutrient rich pond sludge with high biological oxygen demand into receiving waters. This can be prohibitively expensive for smaller producers (Belton et al., 2011). Furthermore, no sustainability standards established to date mandating the recycling of pond sediments through use in terrestrial agriculture.

Global food supplies are heavily dependent on the use of nitrogen and phosphorous fertilizer (Tilman et al., 2002). In recent decades, the use of nitrogen fertilizer has increased many-fold, particularly in low-income countries, contributing to numerous environmental hazards including eutrophication of waterbodies, global warming, groundwater contamination, stratospheric ozone destruction and ecosystem stresses (Crews and Peoples, 2004). Phosphorous is a non-renewable resource, and current global reserves are projected to be depleted within 50–100 years (Cordell et al., 2009). The price of phosphorous is increasing as reserves decline, placing pressures on low-income countries which face additional fertilizer costs for their food production (Cordell and White, 2011). Over-fertilization with phosphorous contributes to excess runoff into waterbodies and associated eutrophication (Cordell et al., 2009).

Consumption of inorganic fertilizer in Bangladesh has risen steadily over time and the country faces a large fertilizer deficit. The share of imported urea increased from 30% in 2005–2006 to 69% in 2010–2011, and the country is almost completely dependent on imports of triple super phosphate (TSP) and muriate of potash (MP) (Ahmed, 2011). Analysis of future demand indicates that the country's inorganic fertilizer requirements by 2050 will total 7.8 million MT, comprised of: 3.9 million MT of urea; 2.2 million MT of TSP, and 1.7 million MT of MP. International fertilizer markets are volatile, and import subsidies represent a burden for the government of Bangladesh (Basak et al., 2015). In the fiscal year 2014, the government paid subsides of BDT 4.66 billion (USD 58.25 million, US$ 1.00 = BDT 80.00) to import of 186,391 MT of urea and 360,682 MT of TSP, MP and other inorganic fertilizers (Financial Express, 2014).

Nutrient rich sediments from fish ponds are a high quality manure, having excellent potential for reuse in crop production. Experimental use of pond sediments as fertilizers for sudangrass and ryegrass in China, produced yields of 112–195 and 65–128 MT ha^{-1} per 6 months, respectively (NACA, 1989). Compared to rice, which is sensitive to excessive nutrient loading, fodder grasses (e.g. para grass, *Brachiaria mutica*) respond well to high levels of nitrogen fertilization (Chadhokar, 1978). Para grass can reproduce sexually from seed, but also reproduces vegetatively by means of its above-ground creeping stolon in open, shallow, tropical freshwater wetlands and flood plains (Hannan-Jones and Csurhes, 2012). The vegetative growth of para grass is very rapid, and it can be harvested at six weeks intervals and fed to cattle (Chadhokar, 1978).

[1] FCR expresses a ratio of the weight of food required to produce a unit gain in the live weight of an animal.