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Comparison of nitrogen balances and efficiencies in rice cum prawn vs. rice cum fish cultures in Mymensingh, North-Eastern Bangladesh

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ABSTRACT

This on-site study is a comparison between integrated rice cum prawn and rice cum fish cultures and their efficiencies in North-Eastern Bangladesh. Common rice cultivation practices in this area often cause environmental problems due to inadequate use of chemical fertilizers and addition of animal feed with fishmeal. Problems include eutrophication and the reduction of soil fertility, as well as the reduction of organic matter content, water holding capacity and the inefficient use of N due to leaching, run-off and denitrification. We evaluated major N inputs of additional feed and chemical N fertilizer into the rice paddy over three field seasons. The N content of rice grain did not increase significantly with fertilizer supply ranging from 41.18 ± 5.57 kg/ha to 57.07 ± 3.62 kg/ha. However, the supply of fertilizer significantly increased the N content of rice straw, consisting of stem, leaf and leaf, ranging from 27.69 ± 6.80 kg/ha to 64.78 ± 2.21 kg/ha. In addition, the supply of feed let to a significant increase of crude lipid per hectare of all integrated animal species, but not of crude protein. These results question the efficiency and economic viability of using chemical fertilizers and feed in integrated cultures. Compared to rice cum fish cultures, unfed and unfertilized rice cum prawn cultures achieved economically satisfying results in terms of the N-output of the major compounds and the N balance (ΔN). Our findings suggest that rice cum prawn cultures without chemical fertilization and without additional feed are economically possible and thus highly recommendable for small scale farmers as they reduce negative environmental impacts. This study can therefore guide future agricultural and aquacultural management practices to help improve fertilization techniques and feed supply.

1. Introduction

In the face of the increasing cost of fertilizers, the deterioration of soil health, environmental pollution and unsustainable crop yields, integrated nutrient management has emerged as a key issue (Aulakh and Pasricha, 1997; Aulakh and Singh, 1997; Zhu et al., 2004; Kim et al., 2011; Sutton et al., 2013). Thus, there is a renewed interest in an alternative source of plant nutrients and integrated agro-aquaculture systems instead of intensifying chemical fertilization (Aulakh and Singh, 1997; Sutton et al., 2013).

Approximately 40% of the world's population depends on rice (*Oryza sativa L.*) as their major caloric source (De Datta et al., 1988; Makino, 2011). Urea is the most commonly used chemical nitrogen (N) fertilizer which is the largest source of N input to and losses from cereal cropping systems including rice. Because rice from paddy fields is a semi-aquatic crop for most of the growing season, losses of nitrate from applied urea can be high due to the difficulties in managing flooded environments, particularly the variable nature of soils and the complex set of N-transformation processes (Chowdary et al., 2004).

A poor use efficiency of N fertilizer in rice paddies is mainly attributed to the losses of N occurring from the paddy through ammonia volatilization, denitrification, leaching, and runoff (Chowdary et al., 2004; Bandyopadhyay and Sakar, 2005; Rimski-Korsakov et al., 2012; Sutton et al., 2013). These losses have detrimental environmental consequences locally and globally; damage and pollution of the atmosphere, eutrophication of the groundwater system and suppression of the natural input of nitrogen due to the decreased efficiency of free-living N fixers in soil, the organic matter content and structure of soil, and its water holding capacity (Vitousek et al., 1997; Bleeker et al., 2011; Delgado and Follet, 2010; Rimski-Korsakov et al., 2012; Liu et al., 2013; Sutton et al., 2013).

Bangladesh is a predominantly agro-based country with one of the highest human population densities worldwide and limited land area. Agriculture is the most important sector in our target research area of Mymensingh. Aquaculture has now emerged as a new opportunity for local fisherman and farmers, who modified their paddy fields into fish and prawn ponds; however the use of

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uncontrolled and high amounts of fertilizer and the excess of animal based feed has led to environmental problems. Therefore, sustainable and economical agricultural practices are the major goals to satisfy the need of the people in rural Bangladesh in terms of nutrition standard and economical sustainability. This long-term study was conducted according to local usage in terms of the preparation of the paddies, fertilization and feeding rate and transplantation of rice to promote integrated cultures in on-farm settings with a critical view on the use of chemical N fertilizer and additional feed in a rural environment.

To our knowledge the present study is the first to evaluate, monitor and compare integrated rice cultures with different species such as prawn and fish simultaneously in terms of the N content of the major compounds (prawn, fish, rice and soil) of each paddy.

Therefore the aims of the study are (1) to demonstrate the influence of different N inputs such as fertilizer and feed on each compound of the paddy such as the animals integrated, rice plants (grain, stem, husk and leaf) and soil in integrated cultures and (2) to compare rice cum prawn (*Macrobrachium rosenbergii*) and rice cum fish (*Oreochromis niloticus* and *Cyprinus carpio*) cultures in terms of the N content of their major compounds.

We have defined N input regimes as urea fertilization for rice and additional feed for the animals and varied the inputs between the treatments to measure and show the correlation of the major compounds for each plot during the experimental period.

The results of this study can be used to optimize management strategies in order to improve the use efficiency of N inputs of integrated rice cultures on a small scale farmer's level.

2. Material and methods

2.1. Experimental site

All three field experiments were carried out on the experimental farm of the Bangladesh Agricultural University, Mymensingh. The geographical location is at 24°75′N latitude and 90°50′E longitude at an altitude of 18 m above sea level. The experiment was carried out in a randomized complete block design following Gomez and Gomez (1984) with a total of fifteen experimental plots. The soil was classified as a non-calcareous alluvial silt clay loam soil with a pH content of 6.2. The N content was 0.19% and a C content of 1.30%.

All paddies were surrounded with an elevated dike with an average height of 0.5 m, to prevent the intrusion of predators such as crabs. Each paddy was outfitted with one outlet, which connected the paddy to one of the two main irrigation channels. Paddies containing fish and prawn were secured by a fine meshed net to prevent the invasion of predators such as snakes and the escape of fish and prawn into the irrigation channels. In the center of each of the fish and prawn paddies, a refuge with a depth of 0.5 m and an area of 4 m^2 was built to ensure a constant water depth for the animals in case of water loss in the surrounding parts of the paddy. The three field seasons were from: June to December 2007 (wet season), January to May 2008 (dry season) and June to December 2008 (wet season).

2.2. Experimental design

In each plot, rice was transplanted at a spacing of 20 × 20 cm (between rows and plants) after 47 days at the nursery for the first season, 74 days for the second season and 44 days for the final season which was described earlier (Mirhaj et al., 2013).

The treatments chosen for this study are related the most commonly practiced systems in Bangladesh such as

(a) Concurrent rice cum fish cultures with chemical fertilization. On one hand, species like *C. carpio*, *O. niloticus*, *Pangasius hyphothalamus, Catla catla, and Labeo rohita* are released into the paddy. On the other hand, *SIS* (*Small Indegeneous species*) who are naturally abundant in the irrigation channels of the paddy are harvested as 'by-catch' for consumption.
(b) Cultivation of shrimp and prawn, mainly using the species *Penaeus monodon* and to a lesser degree *M. rosenbergii*, are cultivated in rotatorial systems. Aquaculture as semi intensive to intensive systems are quite adapted in Bangladesh.

Because our focus is set on integrated rice cultures, we excluded unfertilized monocultured rice paddies because they are very scarce and do not represent local practice on the farmer level. Concurrent paddy systems with *M. rosenbergii* are a very promising approach and showed satisfying results in terms of yields (Mirhaj et al., 2013) and have therefore been added to our treatments. To test the difference of N inputs such as fertilizer and feed, we have designed corresponding treatments that are likely to be adapted of the farmers. Treatments were carried out in triplicates (Table 1).

2.3. Field management

Stubble from the previous season was ploughed into the soil of all plots, following local practice. According to the recommendation of the Bangladesh Rice Research Institute (BRRI, 2004) prior to transplantation of rice all paddies received a basal fertilization of 140 kg/ha triple super phosphate (TSP, $Ca(H_2PO_4)_2$) and 75 kg ha^{-1} muriate of potash (MP, KCl:NaCl). In paddies that received additional urea fertilization (total urea supply: 220 kg ha^{-1}) as the major N-input, only 50% of urea was applied prior to transplantation. The remainder was applied in two equal splits which were during (a) tilling, 20 days after transplantation (DAT), and (b) panicle initiation stage (45 DAT). Crop growth was recorded fortnightly while yields were recorded at the end of each experiment. No pesticides were used during the experimental period (see also Mirhaj et al., 2013).

Supplementary feed as the major N-input for prawn was supplied daily at a rate of 10%, 8%, 6% and 3% of mean body weight during the experiment. The diet composition of prawn feed was 20% fishmeal, 20% wheat flour, 15% soybean meal, 10% mustard oil cake, 10% meat and bone meal, 20% rice bran, 4% molasses, and 1% mineral and vitamin premix (Eskavit Fish Premix, SK + F Bangladesh Ltd.). N content of the feed was determined by a CN Analyzer (Vario MAX CN, Elementar, Germany). It was then converted into crude protein by multiplying the result by the conventional factor 6.25 because proteins contain 16% of N. The crude protein content of the feed varied in each season. It showed values of 24% (1st season), 27% (2nd season) and 24% in the last season (Mirhaj et al., 2013). In unfed treatments the diet consisted of naturally abundant aquatic weeds, benthic organisms and insects in the paddy (Razzak et al., 2010).

Plots containing fish were supplied with supplementary feed as the major N-input at a rate of 6.4 g $kg^{-0.8}$ d^{-1}, which corresponds to two times the maintenance level of fish following Becker et al. (1983). The diet composition was 50% fishmeal, 44% wheat flour, 4% soybean oil, and 2% mineral and vitamin premix (Eskavit Fish Premix, SK + F Bangladesh Ltd.). The chemical composition of the feed varied in each season and is presented in Appendix. Crude protein content ranged from 31% (1st season) to 35% (2nd season) and 30% (3rd season) as it was prepared from local ingredients (see also Mirhaj et al., 2013). Adjustment of fish feed was done fortnightly following Frei and Becker (2005) based on the prospective development of the body mass, assuming a metabolic growth rate of 8 g $kg^{-0.8}$ d^{-1}. The adjustment of prawn feed was done in the