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Sustaining Rice Productivity, Soil Fertility, and Income from Prawn-Rice Joint Culture in the *Gher* System in Bangladesh

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ABSTRACT

This paper examines the long-term impacts of the joint prawn-rice *gher* farming system on agricultural and household incomes, soil fertility, and productivity of modern variety (MV) rice in southwestern Bangladesh, based on socioeconomic data of the *gher* farmers and soil fertility data of their *gher* plots. In 2005, 20 farmers operating on 30 plots were randomly selected from the Bilpabla village of Khulna from whom prawn and MV rice production data were collected using a questionnaire; soil samples were also collected and tested. In 2011 and 2017, the sustainability of the *gher* system over time was assessed through another survey of farmers following the same methodology. Results revealed that although the nominal income from *gher* farming increased by 59 percent in 2011 and 23 percent in 2017, the real income and per capita household income remained unchanged over time. Agricultural income has contributed about 65 percent to household income, which for *gher* farmers was about 200 percent higher than average rural incomes in Bangladesh. Rice productivity declined slightly from its 2005 level. However, the productivity of MV rice under prawn-rice *gher* farming is substantially higher than in the conventional MV rice farming system. The positive estimates of the Mean Soil Quality Index and Soil Degradation Index for land used for MV paddy production within the *gher* indicate an increase in soil nutrients. This suggests that the joint prawn-rice *gher* farming system is relatively sustainable, having improved soil fertility and stabilized real income. Policy implications toward promoting agricultural growth in the southwestern region of Bangladesh include research on developing varieties of MV rice suited to prawn-rice *gher* farming and the development of commercial feeds and markets for prawn to further raise productivity and incomes of *gher* farmers.

Keywords: soil fertility, MV rice productivity, income, prawn-rice *gher* farming, Bangladesh

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INTRODUCTION

Transformation of agricultural land results in changes in cropping patterns along with the ecosystem and the surrounding environment. Rice fields have been transformed into shrimp/prawn farming in coastal areas of tropical Asia and Latin America, which has substantially changed the land use patterns of these areas (Ali 2006). The land use patterns of the southern coastal region of Bangladesh covering Bagherhat, Satkhira, and Khulna districts have been substantially influenced by soil intrusion, salinity, and unavailability of ground water for irrigation for MV rice cultivation and other dry-season crops. In fact, the proportion of fallow land has increased over the years due to soil salinization and scarcity of freshwater for irrigation in the region (SRDI 2012; Kabir, Cramb, and Alauddin 2015).

Shrimp/prawn farming has been recognized as a part of the “blue revolution” in southern Bangladesh since the mid-1980s and has made significant contributions to the local and national economy through foreign exchange earnings and food for coastal residents (Kabir and Eva 2014; Paul and Vogl 2011; Ahamed et al. 2012). Large numbers of male and female workers have been directly or indirectly engaged in different activities of shrimp/prawn farming in Bangladesh. Apart from the overall positive financial and food contribution to the local and national economies, shrimp/prawn farming is posing severe threats to the local ecological and environmental systems, such as soil degradation, soil sedimentation, salinization, pollution, and deterioration of water quality in terms of saline intrusion in groundwater, depletion of mangrove forest and local indigenous fish and local varieties of rice in southern Bangladesh (Wahab 2003; Hoq 1999; Islam 2003; Ali 2004; Hossain, Uddin, and Fakhruddin 2013; Eva 2012).

Commercial shrimp farming has spread and increased rapidly from the mid-1980's in southwestern Bangladesh in the face of high international market demand and its tendency to earn quick money and/or income (Deb 1998;

Neiland et al. 2001; Barmon, Kondo, and Osanami 2004b). However, shrimp-rice farming was seen to exert negative impacts on the environment and ecology (Deb 1998; Dewalt, Vergne, and Hardin 1996; Flaherty, Vandergeest, and Miller 1999; Ali 2004); as prolonged shrimp farming was seen to rapidly diminish soil quality in rice fields and reduced rice productivity substantially. Soil quality of rice fields was believed to have degraded significantly after the introduction of shrimp farming in the region (Ali 2004; 2006).

Prawn-rice joint culture in the *gher* system is an indigenous technology combining aquaculture and agriculture developed and used by local farmers in Southwestern Bangladesh since the mid-1980s. The term *gher* refers to the modification of rice field to prawn and MV rice cultivation. The mid-field (locally known as *chatal*) of *gher* is surrounded by high and wide dikes and canals lying in the periphery of the dikes. The whole area of *gher* is filled with rainwater from June to December and resembles a pond and is used to cultivate freshwater prawn (*Macrobrachium rosenbergii*) and carp. The entire plot becomes naturally dry from January to April except the canals, which retain enough volume of water for MV Boro season (dry winter) rice cultivation.

Prior to *gher* farming, the southwest region experienced a period of severe environmental change during the 1960s and 1980s because of the construction of embankments and polders. This resulted in permanent water logging and increased saline intrusion, causing adverse impact on the production of agricultural crops (Kendrick 1994). After the adoption of *gher* farming system, the cropping patterns have changed, permitting farmers to produce prawn and MV rice together within a year.

Although the impact of shrimp-rice farming on the environment and ecology in the coastal region of Bangladesh was studied by some researchers (Asaduzzaman and Toufique 1998; Aftabuzzaman 1998; Kori 1996; Bhattacharya, Rahman, and Khatun 1999; Rahman 1998; Islam 2003; Ahmed and Garnett 2010; Datta 2001; Islam 2001), similar studies on the prawn-rice *gher* farming system is not widely available. Most of the

studies, which are largely based on cross-sectional data of one period, focused on specific aspects of the *gher* farming system such as history and present and future challenges of *gher* farming (Ahmed, Brow, and Muir 2008; Barmon et al. 2005); input use in MV rice production (Barmon, Kondo, and Osanami 2008a); economic evaluation of MV rice production (Barmon, Kondo, and Osanami 2007b; Barmon et al. 2010); water productivity of MV rice production (Barmon, Kondo, and Osanami 2008b); women's participation (Barmon, Kondo, and Osanami 2007a); labor demand and employment of female workers (Barmon, Kondo, and Osanami 2004a; Rahman and Barmon 2019); child labor participation in prawn fry collection (Ahmed et al. 2009); economics of diversification and production efficiencies (Rahman, Barmon, and Ahmed 2010; Ahmed and Garnett 2010); impact of freshwater prawn farming on globalization and agrarian change (Ito 2004); livelihood of prawn farmers (Ito 2002; Ahmed, Brown, and Muir 2008); economic returns of prawn and shrimp farming (Islam et al. 2005); prawn and shrimp marketing (Ahmed et al. 2009; Islam 2008); and energy productivity and energy use efficiency of the *gher* system (Rahman and Barmon 2012; Rahman and Barmon 2018). Only Ahmed, Brow, and Muir (2008) and Chowdhury, Shivakoti, and Salequzzaman (2006) qualitatively discussed sustainability of *gher* farming system in southwest Bangladesh.

Given the serious concerns on adverse impacts of shrimp-rice farming, it is important to examine the longer-term impacts of prawn-rice *gher* farming system because it is completely different from the traditional shrimp-rice farming system in terms of feeding, cultivation practice, and the production environment. For example, shrimp culture requires brackish water whereas prawn culture uses freshwater. Consequently, prawn-rice *gher* farming system has potentially different impacts, but such information is not widely available in the literature.

The present study covers a 13 year period (2005–2017), using three rounds of socioeconomic survey and soil sample data collected from the same 20 farmers operating on 30 *gher* plots in

2005, 2011, and 2017 from Bilpabla village of Khulna district in southwestern Bangladesh. The detailed information presented in this study could help guide policymakers and researchers in further developing the prawn-rice *gher* system and agricultural development planning for Bangladesh.

MODES OF SHRIMP/PRAWN PRODUCTION IN BANGLADESH

The southwestern parts of Bangladesh have some natural advantages in shrimp/prawn production. Shrimp/prawn culture has been practiced in rivers, tidal channels, and the coast over a long time in Bangladesh. The production cost of shrimp/prawn is lower compared to other countries of the world due to the availability of abundant water, land, and fry resources. The country possesses one of the world's largest resources of wild shrimp and prawn fry in the Bay of Bengal. The two types of *gher* farming operated in Bangladesh are (1) brackish water-based shrimp-rice culture and (2) fresh water-based prawn-rice culture. Shrimp *gher* farms are larger in size and scale and need saline water, whereas prawn *gher* farms are comparatively smaller in size and scale and need fresh water. Traditionally, shrimp is cultured in the low lying coastal and peri-coastal regions and prawn is cultured in the upper elevation areas of Bagerhat, Khulna and Satkhira districts.

Traditional Shrimp-Rice Culture

Shrimp culture in Bangladesh still follows the traditional *gher* farming method wherein the flow of saline water into the enclosed areas is controlled by small wooden sluice gates. These sluice gates are opened to allow entry of saline water into the *gher* from February to April and at that time the juveniles of various varieties of coastal finfish and post larvae of shrimp that breed in the sea enter the *gher*. After April, the gates are closed and shrimps are grown until they reach harvestable size within four to five months, with shrimps usually grown on natural feeds. In the lower regions of Bagerhat, Khulna, and Satkhira districts, the local variety of

Aman rice (monsoon season) is cultivated from July–December after the harvesting of shrimp.

Prawn-rice joint culture in the gher system

The *gher* for freshwater prawn farming is a modified rice field with high and wide dikes and a canal inside the periphery of the dikes that retains water during the dry season. At the early stage of *gher* farming, most of the farmers cultivated prawn in monoculture ponds, but recently, the farmers have commonly grown carps with prawn. In addition to rice, vegetables and fruit trees are also grown in this integrated *gher* farming system (Figure 1) (adopted from Barmon, Kondo, and Osanami 2008b).

The *gher* cycle begins in May/June when the farmers release prawn post larvae into the *gher*. Prior to this, farmers repair the dikes and trenches almost every year. To reduce soil acidity, lime is used during the *gher* preparation. During the growing period, supplementary feeds are given to the prawns. Traditionally, snail meat was used as feeds, but nowadays, farmers use a wide range of

homemade and commercial supplementary feeds to increase productivity. Carp fish fingerlings are released into the *gher* in May/June and cultured for nine months until adequate water is retained. Usually, no specific supplementary feeds are provided for carps as they only share feeds supplied for prawn. Farmers usually grow vegetables during both winter and summer seasons on the dikes, and some farmers grow vine-type vegetables inside the *gher*.

In the *gher* farming system, farmers usually grow MV Boro rice (dry winter season) on *gher chatal* (the land inside the *gher*) during the winter season between January and April. Farmers irrigate the rice field from the surrounding canals inside the *gher* using mechanical pumps. *Gher* farmers do not use any type of inorganic fertilizer for MV Boro rice production. Farmers provide different types of feed in the *gher* during prawn and carp production. The feed unconsumed by the prawn and carp naturally fertilize the rice field, from which rice plants absorb nutrients from within the *gher*.

Figure 1. Diagram of RPG system in rainy and winter seasons and irrigated system and soil fertility process for MV paddy production

MATERIALS AND METHODS

Study Area

Bilpabla is one of the typical villages in Dumuria Thana (sub-district) located about 7 km west of Khulna district and about 310 km south of the capital Dhaka. The village is divided by a small river and the households are situated on both sides of the river (Figure 2). The land area is defined as medium high in altitude and the soil quality is alluvial, loamy, and sandy. Bilpabla village was selected purposely because it is one of the typical villages with dominant *gher* farming practice. The demographic characteristics of the village are very similar to other villages where prawn-rice *gher* farming is being practiced. Among 401 households in 2003, 332 households own *gher* farmland and the remaining 69 households do not own any. In the same year, the average *gher* farming size was 0.80 ha, of which 0.34 ha was owned and 0.46 ha was rented for *gher* farming.

Figure 2. The location of study area and rice-prawn *gher* farming

Survey Data

Two sets of data, socioeconomic data of rice and prawn production and soil sample data of the rice field inside the *gher*, were used to examine the impacts of prawn-rice *gher* farming. Socioeconomic data of rice and prawn production were collected through a comprehensive questionnaire, and soil samples were tested in the laboratory. Twenty farmers owning 30 *gher* plots were randomly selected from Bilpabla village, while soil samples were collected from the plots before and after MV rice production. The three rounds of farm surveys were carried out for the same 20 *gher* farmers during the months of October 2006, October 2012, and October 2018 based on the agricultural cropping year 2005, 2011, and 2017, respectively.

Soil Sampling

Each sample of soil collected is a good mixture of nine sub-samples from nine different places of a specific *gher* plot. The soils were taken from 0–15 cm depth, which represent the cultivated topsoil (BARC 1997). The sampled soils were then placed in transparent polythene

bags and then dried well under natural sunshine and labeled numerically for identification. The soil samples were then sieved through a 20-mesh sieve to make the samples suitable for chemical analysis (Hesse 1971; Jones and Case 1990; Petersen 2002). The first batch of soil information was collected just before MV rice, and another batch was collected just after harvesting MV rice from the same plot. For both sampling times, soil samples as well as plot numbers were identified with the same numerical value.

For the entire study, a total of six batches of soil information were collected in three rounds of survey periods in 2005, 2011, and 2017. After sieving, the labeled samples were sent to the laboratory of the Soil Resource Development Institute (SRDI) of Bangladesh in Dhaka for chemical analysis. Averages of the soil properties were collected to determine changes in the soil information over time.

Soil Analytical Methods

Soil chemical properties were analyzed by routine methods. Soil salinity was measured as

electrical conductivity (EC-dS/m; 1:5) using a conductivity meter (Rhoades 1982) and soil pH was measured using a glass electrode pH meter (H₂O, 1:2.5 and pH [KCl, 1:2.5]) (McLean 1982). Organic matter (OM) and total nitrogen (TN) were measured using oxidation and the micro-Kjeldahl method, respectively (Bremer and Mulvaney 1982; Nelson and Sommers 1982). Available soil phosphorus (P), and exchangeable potassium (K), calcium (Ca), and magnesium were analyzed using the Olsen method (Olsen and Sommers 1982) and ammonium acetate extraction method (Barker and Surh 1982). Available boron (B), available zinc (Zn) and copper (Cu) were extracted with 0.1 mol/L HCl and easily reducible Mn. However, other relevant soil salinity parameters such as exchangeable sodium percentage and cation exchange capacity were not measured.

Analytical Techniques

Computation of soil degradation index

Soil degradation results in diminished capacity of the ecosystem to provide goods and services for its beneficiaries and deteriorates the capacity to sustain higher yields of agricultural crops (Dumanski and Pieri 1997; FAO 2018). Soil degradation is generally measured by comparing variation between present and earlier conditions of certain soil properties of a particular area in terms of chemical, physical, and biological properties under different land uses (Riquier 1978; Adejuwon and Ekande 1988; Islam and Weil 2000; Bremer and Ellert 2004). To examine the severity of soil degradation caused by prawn-rice *gher* farming in the study area, the following steps were done. First, the mean values of each of 15 soil chemical properties of the soil samples from the 30 plots were separately computed for the years 2005, 2011, and 2017. Second, percent change in mean values of each soil property during 2005–2011, 2005–2017, and 2011–2017 were computed. Finally, percent change in values of all 15 soil properties were added and then averaged to obtain the Mean Soil Quality Change Indicator (MSQI) of prawn-rice *gher* farming system. It was assumed that larger negative value of MSQI indicates higher degrees

of soil degradation due to prawn cultivation and positive value of MSQI indicates improvement in soil qualities of the *gher*. Finally, the composite Soil Degradation Index (SDI) of land use for MV rice production in 2005, 2011, and 2017 were computed by calculating the percentage difference in their respective values of MSQI from the base period value of MSQI in 2005. Higher negative differences indicate severe soil degradation and higher positive differences indicate increased soil fertility. Thus, the present study has combined two conventional methods to assess soil degradation/soil fertility occurred due to MV rice production under the prawn-rice *gher* farming system.

Kruskal-Wallis Test

The following Kruskal-Wallis test was used to check the differences in real gross revenue, real agricultural income, and real household income of prawn-rice *gher* farming system in the cropping years 2005, 2011, and 2017:

$$H = \frac{12}{n(n+1)} \left[\frac{(\sum R_i)^2}{n_i} \right] - 3(n+1) \text{ with } (k-1) \text{ d.f.}$$

The Kruskal-Wallis H test statistic follows Chi-square distribution, n_1 , n_2 , and n_3 are sample size of prawn-rice *gher* producers and n is the sum of all prawn-rice producers in cropping years 2005, 2011, and 2017, respectively. $\sum R_i$ is the sum rank of real gross revenue, agricultural income, and household income of the prawn-rice producers in 2005, 2011, and 2017 ($i = 1, 2, 3$).

RESULTS AND DISCUSSIONS

Impact on Soil Fertility

Changes in soil properties and soil fertility

Prawn-rice *gher* farming system can potentially affect soil properties of MV rice production in several ways. For MV rice production mainly, chemical fertilizers, pesticides, and irrigation are the necessary inputs. While chemical fertilizers are the main source to enhance soil fertility for MV rice production in the conventional

system, nutrients from leftover feeds of prawn production, feces/excretion of prawn and carp, and algae and fungi are the main source of soil nutrients in the *gher* farming system. Although the transformation of rice fields into prawn-rice *gher* farming reduces the total rice field area by 40 percent, increased MV rice productivity and fodder (straw) with improved soil quality make up for the shortfall in land area. Changes in soil properties of the rice field in *gher* farming are presented in Table 1.

Soil pH

Soil pH and base saturation are the important chemical properties that influence soil nutrient availability and plant growth, the activities of soil microorganisms, and OM decomposition. Plants normally cannot tolerate acidic or alkaline soils, although rice crops usually prefer slightly acidic soils. The mean pH of soil in the rice field in *gher* farming system was estimated at 7.20 in 2005. The corresponding figures changed to 6.93 in 2011 and 6.99 in 2017, indicating that the pH level of soils in the mid paddy field of joint prawn-rice

gher farming system remains neutral in MV paddy cultivation.

Electrical conductivity

Electrical conductivity (EC) measures the amount of total dissolved salts in the soil and is often used for delineating other soil properties. It appears from Table 1 that the mean values of EC were 5.66 decisiemens per meter (dS/m) in 2005, 5.52 dS/m in 2011, and 5.80 dS/m in 2017. Most of the *gher* farms are in the southwestern part where soils are comparatively more saline than other areas in Bangladesh, and thus provide a compatible production environment for shrimp/prawn. Shrimp-rice *gher* farms are located nearer to the sea and require brackish water, whereas prawn-rice *gher* farms are located far from the sea and require freshwater.

The results imply that although salt has accumulated by harvest time, slightly higher level of soil salinity did not hamper plant growth substantially (SRDI 2010). The main reason is that the rice areas of *gher* plots get washed away during the rainy season when prawn is cultured. As a

Table 1. Descriptive statistics of soil fertility status (0–15 cm) in rice-prawn *gher* farming system in Bilpabla village, Khulna district

Soil property	2005				2011				2017			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
pH	7.20	0.50	5.60	8.50	6.93	0.46	5.30	7.60	6.99	0.30	5.35	6.80
EC (ds/m)	5.66	0.59	3.39	8.94	5.52	0.54	1.71	9.25	5.80	0.31	3.80	6.53
TN (%)	0.41	0.05	0.24	0.68	0.46	0.10	0.19	0.69	0.47	0.06	0.29	0.68
OM (%)	11.74	0.50	6.26	15.78	11.87	0.97	3.80	13.75	11.86	0.68	7.23	12.61
Potash (K)	1.11	0.14	0.62	2.25	1.11	0.32	0.25	2.31	1.20	0.29	0.39	1.83
Ca	29.59	0.92	15.50	40.90	30.14	1.85	17.81	39.72	32.79	2.28	15.55	45.85
P	10.90	0.90	2.21	35.50	11.17	1.73	2.30	17.75	10.97	0.81	3.18	11.45
Zn	1.88	0.42	0.70	6.31	1.90	0.39	0.30	3.37	2.16	0.40	0.56	3.50
Sulphur (S)	204.35	5.90	49.10	396.10	226.30	82.70	44.70	390.00	237.30	83.17	44.70	454.70
Manganese (Mn)	92.46	1.91	44.70	192.80	101.19	3.31	49.05	193.59	107.39	4.41	55.20	207.80
B	2.46	0.30	1.44	3.87	2.46	0.32	0.26	2.38	2.57	0.22	0.58	2.26
Cu	10.27	5.35	4.92	18.12	11.95	1.52	7.72	18.48	12.59	1.50	8.51	22.19
TN	26.56	2.96	2.20	9.50	5.68	0.52	4.39	6.98	6.68	0.54	5.43	8.05
Total Carbon (C)	76.86	9.33	26.50	144.00	77.42	4.27	52.22	69.45	78.83	3.71	39.35	84.00
C/N ratio	12.60	0.63	11.00	15.00	12.76	1.55	9.54	13.89	13.09	1.52	8.33	17.33

Source: Laboratory experiments (2006, 2012, and 2018)

Notes: Soil sample size = 30 from 20 *gher* farmers; SD = standard deviation

result, the natural salt did not accumulate in rice fields as happened with the usual prawn farming (Barmon et al. 2010).

Total nitrogen (%)

The critical value of TN (%) of clay soil in wetland rice field in southwestern Bangladesh is 0.12 (BARC 2018). The TN (%) content in the soil of mid-rice fields of joint prawn-rice *gher* farm was estimated at 0.41 in 2005, 0.46 in 2011, and 0.47 in 2017, which were significantly higher than the critical level. The implication is that the leftover feeds azolla and algae enhance TN availability, which potentially improves MV rice productivity to some extent (Barmon et al. 2010; Islam et al. 2015).

Organic matter (%)

After harvest, the rest of the rice plant (root and shoot) remains in the field along with naturally grown aquatic ferns (azolla), and algae in the mid paddy field, which then decompose into the soil and are converted into OM (Barmon et al. 2010). The critical value or standard level of OM (%) in soil is 5 with higher value of OM (>5%) indicating increased soil fertility and productivity, and lower value (<5%) indicating soil degradation (BARC 2018). On average, the total OM in the soils of rice fields in the *gher* farming system was computed at 11.74 in 2005, 11.87 in 2011, and 11.86 in 2017, significantly higher than the standard level of OM (>5%) for quality soil for crop production (BARC 2018). This indicates that over the years, OM (%) content in the soil of prawn-rice *gher* farming remained stable at a level that is naturally much higher, thereby potentially more beneficial to MV rice productivity. On the other hand, OM content were found to decrease rapidly in MV rice fields under the shrimp-rice farming system, possibly going below the standard level recommended by BARC, thereby adversely affecting MV rice productivity in the coastal region of Bangladesh (Ali 2004; 2006).

Carbon nitrogen ratio

The Carbon Nitrogen (C/N) ratio of soils was almost the same in the *gher* farming system

in 2005, 2011, and 2017. The C/N ratio lies between 8:1 to 30:1, however, the critical limit is 10:1 (BARC 2018). The C/N ratio was about 13:1 in the soil MV paddy cultivation during the period 2005 to 2017, which is a very satisfactory level of the extent of nitrogen immobilization in soils for MV paddy production in joint prawn-rice *gher* farming system. This indicates that the *gher* farming system has substantially improved soil quality, which may have enhanced MV rice productivity in the study area.

Available phosphorus

Table 1 shows that the mean level of available P varies from 10.90 µg/g soil to 11.17 µg/g during the period, which is higher than the critical limit of 7 µg/g soil (BARC 2018). This indicates that soils of *gher* plot retains available P suitable for MV paddy cultivation for the next year.

Total carbon

Soil organic carbon (C) is the biggest part of the soil OM and it is considered as the most important indicator of soil quality and productivity through its positive effects on soil structure, water storage capacity and nutrient supply (Milne et al. 2010; Barmon et al. 2010). Soil organic carbon also plays a vital role in soil formation and is strongly correlated with soil organic nitrogen, which helps to improve soil productivity in cropland (Gaiser and Stahr 2013). Table 1 shows that on average, the available total organic C in the soils of rice field in *gher* farming system was 76.86 g/kg (2205), 77.42 g/kg (2011), and 78.83 g/kg (2017), respectively. The implication is that the total carbon very slowly increased over the years 2005 to 2017, indicating that soils in the *gher* farming system became more fertile over the years.

Potassium, calcium, zinc, sulphur, manganese, copper, and boron

Table 1 shows that the estimated mean values of K, Ca, Zn, S, Mn, Cu and B were almost the same in 2005, 2011, and 2017 under the joint prawn-rice *gher* farming system. This indicates that the *gher* farming system maintains K, Ca, Zn, sulfur (S), manganese (Mn), Cu, and B in soils over

time. The main reason is that farmers apply various types of feeds during prawn and carp production during the rainy season because they believe that the leftover feeds and naturally grown aquatic ferns (azolla) and algae in the mid paddy field of *gher* farming make the soil fertile for MV rice production, as revealed by farmers in field surveys in 2018, which is not possible in traditional year-round MV rice production system (Barmon et al. 2010).

Accumulation of N, P, and S

Chemical fertilizers such as urea, muriate of potash (K_2O), triple super phosphate (TSP), gypsum, and zinc sulfate ($ZnSO_4$) are the main inputs along with irrigation and MV rice seeds for traditional year-round MV rice production. Farmers provide various types of supplementary feed such as homemade feed, meat of mud snail, and processed feed during the growth period of prawn (May–November). The ingredients of homemade feed include oilcakes, polished rice, wheat bran, wheat, fish meal, and other feeds in fixed proportions. Farmer-repondents believe that nutrients from leftover feeds of prawn production and feces of prawn and carp fish decompose naturally into azolla and algae. This releases N, P, and S in soils in the *gher*, making the soil more fertile. Consequently, farmers apply very small amounts of urea, muriate of potash, triple super phosphate, gypsum, and $ZnSO_4$ for MV rice production. In contrast, sulfide rich tidal water is required to cultivate shrimp and MV rice in the joint shrimp-rice *gher* farming, which accumulate more S than the critical level in the mid rice field, reducing MV rice productivity over time (Ali 2004; 2006).

Soil acidity and salinity status

The soil samples collected in 2005, 2011, and 2017 showed that soil pH in MV rice fields of the sampled *gher* plots were almost same over the years, with the pH values close to 7.0 or neutral, implying that soil acidity did not increase in rice field due to prawn culture in the *gher*. The main reason is that MV Boro rice production starts from the end of December and finishes at the end of April in

gher farming system. In *gher* farming system, water drains into canals or sometimes a small amount (6–10 in) of water remains on the mid-field (*chatal*) at the end of December depending on the location and altitude level of *gher* plots. At that time, farmers prepare land to transplant MV rice on the topsoil. As the topsoil of the mid-field of *gher* is clay soil, no irrigation is required for soaking of the topsoil for transplantation as it retains an adequate amount of water. Sometimes, when water drains into the canal and the topsoil becomes dry, irrigation is required to soak the land to prepare for transplantation. Recently, farmers have made new canals inside *gher* plots and filled the old canals using soil from the new canals. The transfer of soils improves soil fertility to a level optimum for MV rice as well as prawn production. Farmers believe that if the position of canals shifts every 3–4 years, then soils become more fertile for crop production. In contrast, ground water irrigation is required to cultivate MV rice under shrimp-rice *gher* farming and soils in the rice fields become more acidic over the years due to prolonged trapping of tidal water in shrimp ponds. The sulfur from the sea water precipitates to the bottom of the ponds as sulfide deposits which at the end of the rice cultivation are then exposed and oxidized, releasing sulfuric acid to the soil, thereby increasing its acidity and salinity (Ali 2006).

On the other hand, the values of EC of soils in the rice plots under prawn-rice *gher* farming were almost the same over the period 2005, 2011, and 2017. This implies that soil salinity did not increase significantly in prawn-rice *gher* farming, although the actual values are >4 dS/m, which indicates presence of some salinity (BARC 2018). The main explanation for stable salinity is that the farmers in prawn-rice *gher* farming irrigate rice fields from canals that retain adequate amount of surface water. Moreover, the rice fields in prawn-rice *gher* farming system washes out harmful excessive salt and sulfur thereby assisting in reducing the extent of soil salinity that could seriously affect plant growth. In contrast, low-lift pump irrigation along with tidal sea water is used to cultivate MV rice production in shrimp-rice *gher* farming, resulting to increased salinity over the years (Ali 2004; 2006).

MSQI and SDI of soil status

The computed values of MSQI of land use for MV rice production under prawn-rice *gher* farming system were 5.04, 5.31 and 10.80 for the periods 2005–2011, 2011–2017 and 2005–2017, respectively (Table 2). This indicates that the production structure and process of feeding for prawn production and irrigation system of MV rice cultivation under the prawn-rice *gher* farming system may have substantially improved soil quality over the years from 2005 to 2017. Similarly, the values of SDI of the MV rice production during the periods 2005–2017 and 2011–2017 were 5.32 and 114.20, respectively, which are also positive thereby indicating that the soil quality of rice fields in prawn-rice *gher* farming system had improved over time from 2005 to 2017. It may thus be concluded that the joint prawn-rice *gher* farming system is relatively sustainable in terms of improving soil fertility levels of the MV paddy field located within the *gher* system.

Impact on MV Rice Productivity (Yield/ha)

Agricultural productivity is measured as the ratio of agricultural outputs to agricultural inputs. In this study, MV rice productivity mainly depends on irrigation facility, application of

chemical fertilizers, varieties of seed used and the production environment. The per hectare yield of MV rice was used as the principal measure of MV rice productivity.

The actual yields (kg/ha) of MV rice under prawn-rice *gher* and year-round MV rice farming system have fluctuated over the years from 2005 to 2017 (Table 3). The apparent overall decline is insignificant as compared to the base year of 2005. The main reason is that the farmers were more enthusiastic to produce MV rice at the introduction of joint prawn-rice *gher* farming. In addition, the yield (kg/ha) has fluctuated over the year due to uncontrollable environmental factors such as rainfall, temperature, etc. (field survey 2017). In contrast, the average yield of MV paddy in conventional year-round rice farming increased from 3,997 kg/ha in 2005 to 4,425 kg/ha in 2017 in Lebubinia village located next to Bilpabla village (Barmon et al. 2010; field survey 2018).

Impact on Income

Costs and returns of prawn-rice *gher* farming

Total input costs of prawn and MV rice production, gross return, net profit, and agricultural income as well as household income of prawn-

Table 2. Mean Soil Quality Index of MV paddy production in joint rice-prawn *gher* farming system

Soil Properties	2005	2011	2017	2005–2011 (% Change)	2011–2017 (% Change)	2005–2017 (% Change)
pH	7.20	6.93	6.99	-3.75	0.87	-2.92
EC (ds/m)	5.66	5.52	5.80	-2.47	5.07	2.47
TN (%)	0.41	0.46	0.47	12.20	2.17	14.63
OM (%)	11.74	11.87	11.86	1.11	-0.08	1.02
Potash (K) (mg/100g soil)	1.11	1.11	1.20	0.00	8.11	8.11
Ca (mg/100g soil)	29.59	30.14	32.79	1.86	8.79	10.81
P (µg/g soil)	10.90	11.17	10.97	2.52	-1.79	0.69
Zn (µg/g soil)	1.88	1.90	2.16	1.06	13.68	14.89
Sulphur (S) (µg/g soil)	204.35	226.30	237.30	10.74	4.86	16.12
Manganese (Mn) (µg/g soil)	92.46	101.19	107.39	9.44	6.13	16.15
B (µg/g soil)	2.46	2.46	2.57	0.00	4.47	4.47
Cu (µg/g soil)	10.27	11.95	12.59	16.36	5.36	22.59
TN (g/kg)	4.56	5.68	6.68	24.56	17.61	46.49
Total Carbon (C) (g/kg)	76.86	77.42	78.83	0.73	1.82	2.56
C/N ratio	12.60	12.76	13.09	1.27	2.59	3.89
MSQI	-	-	-	5.04	5.31	10.80
SDI	-	-	-	-	5.32	114.20

Source: Laboratory experiments (2006, 2012, and 2018)

Notes: Soil sample size = 30 from 20 *gher* farmers; SD = standard deviation

Table 3. Actual yield (kg/ha) of MV paddy in PRG and YRMV farming system in 2005, 2011, and 2017

Cropping Year	Prawn-Rice <i>Gher</i> (PRG) Farming					Year-Round MV (YRMV)
	Mean	SD	Min	Max	Rank sum	Mean
2005	5,188	416	1,580	4,346	829.0	3,997 ^a
2011	4,720	398	3,769	5,399	443.5	NA
2017	4,841	428	3,769	5,531	557.5	4,425 ^b
Kruskal-Wallis statistic	12.859***					

Sources: Field surveys (2006, 2012, 2018); ^aBarmon et.al. (2010); ^bField Survey (2018)

Notes: *** denotes statistically significant at 1 percent level; NA indicates that data is not available

rice *gher* farmers were computed. The total cost items in *gher* farming include prawn and carp fingerlings cost, various kinds of feed cost, labor, medicine, watching/security cost, seed/seedling cost of rice and vegetables, land preparation cost (bullock power), irrigation, pesticides and fertilizer costs. On the return side, gross return includes revenue from prawn, carp, rice, and vegetables. The calculation procedure for variable cost, fixed cost, labor cost, gross revenue, net profit, and agricultural income are explained below.

Variable costs

Variable costs, which comprise the largest share of total cost of *gher* farming include prawn and carp fingerling costs, feed cost, medicine cost and all labor cost (family supplied labor, permanent and temporary hired labor) for prawn and carp production. These also include seedling costs of rice and vegetables, land preparation cost, irrigation, pesticides and fertilizer costs and labor cost for rice and vegetable production. The variable costs of prawn and MV rice production are presented in Table 4. All variable costs (input costs) of prawn production under *gher* farming (for the average *gher* farm size of 0.83 hectare) are estimated at Bangladeshi Taka¹ (BDT) 149,714, BDT 273,655, and BDT 459,152 in 2005, 2011, and 2017, indicating that the nominal input costs have increased by 83 percent in 2011 from 2005

and 68 percent in 2017 from 2011, respectively. The main reason is that all input costs have significantly increased (mainly prawn fingerling and feed costs) over the period. Similarly, the total input costs of MV rice production under *gher* farming have also increased by 76 percent in 2011 from 2005 and 66 percent in 2017 from 2011, respectively, mainly because of higher input price.

Fixed costs

The fixed costs considered here are the maintenance cost and the depreciation costs of construction of *gher* farming, the preparation cost of monitoring house, and land rent. The land rent is considered as the amount paid by the tenant farmer to the landlord. In the case of landowner-farmers, the land rent is calculated based on the present value of land rent that the landowner-farmers could have earned by renting out their land. The components of fixed costs are also presented in Table 4. It shows that total fixed cost has increased by 52 percent from 2005 to 2011 and 61 percent in 2017 from 2011, respectively. The main reason was that the socioeconomic status of *gher* farmers had improved simply because of the profit generated from *gher* farming. As a result, the family labor also engaged in working in their owned *gher* plots. They hired labor for maintaining and repairing dikes and uprooting grass on the sides of *gher* plots. Even though per unit rent of *gher* plots doubled in 2011 and 2017, the amount of rent in total fixed cost remains very small. The fixed costs per unit *gher* plot has increased significantly in 2017 because of

1 USD1.00 = BDT 66.20 (2005); BDT 81.83 (2011); BDT 82.67 (2017)

Table 4. Production costs and returns of prawn-rice *gher* farming (BDT)

Particulars	2005	2011	2017
A. Variable costs of prawn and fish production:			
Prawn fingerlings	59,630	52,246	55,698
Carp fish fingerlings	2,140	15,025	17,040
Feed	56,275	146,856	279,760
Medicine	1,617	2,608	4,150
Hired labor	18,734	34,630	68,590
Sub total	138,396	251,365	425,238
B. Variable costs of paddy and vegetables production:			
Paddy seed/seedlings	1,005	1,841	1,936
Vegetables seed/seedlings	126	211	473
Land preparation (bullock)	1,802	1,825	2,215
Hired labor	5,608	12,896	21,865
Irrigation	515	1,905	3,135
Pesticides	1,081	1,215	1,525
Fertilizer	641	1,492	1,905
Machinery cost	540	905	860
Sub total	11,318	22,290	33,914
C. Total variable costs (A+B)	149,714	273,655	459,152
D. Fixed costs:			
Depreciation cost of <i>gher</i> preparation	1,599	2,976	4,024
Opportunity cost of land	19,525	37,650	55,100
Opportunity cost of family labor	13,747	12,937	30,925
Land rent	4,800	6,700	6,900
Total fixed costs	39,671	60,263	96,949
E. Total costs (variable and fixed costs) (C+D)	189,385	333,918	556,101
F. Revenue from prawn and fish:			
Prawn	274,275	444,740	669,863
Carp fish	24,420	54,475	84,980
G. Revenue from paddy and vegetables:			
Paddy	31,825	45,728	62,358
By-product of paddy	2,228	5,720	6,925
Vegetables	1,228	1,650	2,568
H. Total revenue (F+G)	333,976	552,313	826,694
I. Net profit (H-E)	144,591	218,395	270,593
CPI	100	157	220
J. Real net profit	144,591	139,469	123,075

Source: Field surveys (2006, 2012, 2018)

Notes:

USD 1.00 = BDT 66.71 (2006); BDT 79.68 (2012); BDT 83.60 (2018)

Surveyed average *gher* farm size was 0.90 ha

Sample size was 20

Depreciation of construction of *gher* and monitoring house were calculated by the straight-line method. In this method, depreciation is to divided total expected depreciation equally among the expected number years of the life of the *gher*. It works fairly well for purpose of analyzing the farm business (Hopkins and Heady 1955). Based on the farm survey data, the economic life of *gher* farming was considered as 25 years.

higher opportunity cost of family-supplied male and female labor and rent of *gher* plots in the study area.

Labor cost

Labor cost, which was one of the main cost items in *gher* farming, includes cost of family labor, permanent and temporary hired labor. The family labor cost was calculated based on opportunity cost at the current market rate of hired labor. The hired labor cost was simply the local agricultural wage. Most of the labor cost was incurred in harvesting of prawn and cleaning the *gher* (Table 4). The wage rate of temporary and permanent hired labor for males and females both for prawn and MV rice production has increased significantly in 2011 and 2017 as compared to 2005. The wage rate for hired male labor was BDT 120/day in 2005, whereas it increased to BDT 250/day and BDT 500/day in 2011 and 2017, respectively.

Gross revenue and net profit

Gross revenue is calculated by multiplying the total volume of production of the farm by the farm-gate price. Net profit is calculated by subtracting total production cost (fixed and variable costs) from gross revenue. Total agricultural income of the *gher* farmers who cultivated their own *gher* plots includes net profit of *gher* farming, opportunity cost of family labor and land cost. The income of the farmers who rented *gher* plots from the landlords includes net profit of *gher* farming and opportunity cost of family labor for rented farmer. Table 4 shows that total gross revenue of joint prawn-rice *gher* farming was BDT 333,976, BDT 552,313 and BDT 826,694 in 2005, 2011 and 2017, respectively, indicating that the nominal gross revenue has increased by 65 percent in 2011 from 2005 and 50 percent in 2017 from 2011, respectively and it was the collective contribution of all inputs used in joint prawn-rice *gher* farming to produce prawn and MV paddy. The amount of net profit of joint prawn-rice production under *gher* farming was BDT 144,591, BDT 218,395 and BDT 270,593 in 2005, 2011 and 2017, respectively, which indicates that the nominal profit has increased by 51 percent from 2005 and 24 percent

in 2017 from 2011, respectively. However, when real profit was computed by deflating nominal values using national consumer price index, the differences are not statistically significant.

Household income of gher farmers

In general, there are three main sources of income of agricultural households in Bangladesh. These are: (1) profit from agricultural production, (2) agricultural labor wage income, and (3) income from non-agricultural activities. The agricultural profit is the sum of crop income and income from livestock and poultry. Similarly, agricultural labor wage income includes both family labor used on own farm and labor sold to other farms. Finally, non-agricultural income can be decomposed into earnings from self-employment, wage received in rural non-farm labor markets and remittances from household members working in urban areas (Renkow 2000).

The value of agricultural income, its components and percentage (%) share of household income are presented in Table 5. It is evident that agricultural income remains the principal source of income for households of the sampled *gher* farmers, which has increased considerably over the sample period in nominal terms. The amounts of agricultural wage, opportunity cost of family members, and off-farm income were almost the same in the contribution to total household income. The agricultural wage income accounts for only 5 percent for *gher* farmers, indicating that family members may have enjoyed more leisure time and engaged in other off-farm activities. The amount of opportunity cost of *gher* land contributed about 9 percent, 11 percent, and 13 percent to net household income in 2005, 2011 and 2017, respectively. The percentage contribution of opportunity cost has increased slightly during the period simply due to increase in market value of the prawn output. The income from livestock was estimated at about 9 percent, 10 percent, and 7 percent to net household income in 2005, 2011, and 2017, respectively. The contribution of off-farm (about 2%) and homestead gardening (less than 1%) income to net household income were very negligible. Annual

total nominal household income of *gher* farmers increased from BDT 214,843 in 2005 to BDT 341,527 in 2011, and to BDT 420,846 in 2017. In real terms, household income had increased slightly by 1.52 percent from 2005 to 2011, and decreased by 12 percent from 2011 to 2017. Annual average household income in rural areas in Bangladesh was BDT 115,770 in 2011 and BDT 160,236 in 2017 (BBS 2011; 2018).

Table 5 shows that the total nominal household income of *gher* farmers is nearly 200 percent higher than the income of rural areas of Bangladesh. The table also shows that the nominal agricultural income has contributed about 65 percent to nominal household income during the period 2005 to 2017. The nominal agricultural income increased by 51 percent from 2005 to 2011, and 23 percent from 2011 to 2017. It can be concluded that the prawn-rice *gher* farming system

has increased total nominal household income over the study period in this area as compared to other rural areas in Bangladesh.

Changes in real income from all sources

In this section, an attempt is made to determine the changes in real income gained from *gher* farming system and other sources for three cropping years 2005, 2011 and 2017.

Nominal and real total gross revenue from *gher* farming, agricultural income, and total household income of *gher* farmers in cropping years 2005, 2011 and 2017 are presented in Table 6. It is evident from Table 6 that although nominal values of these three sources of income have changed substantially, the real values of these incomes did not change significantly over the 13-year period under consideration. This is mainly due to high rate of inflation persisting in

Table 5. Household income of rice-prawn *gher* farmers (BDT)

Sources of income	2005	2011	2017
Profit/agricultural income	144,591 (67.30)	218,395 (63.95)	270,564 (64.29)
Opportunity cost of family labors	13,747 (6.40)	35,600 (10.42)	30,925 (7.35)
Opportunity cost of land	19,525 (9.09)	37,650 (11.02)	55,100 (13.09)
Agricultural wage (male and female)	12,155 (5.66)	16,175 (4.74)	24,745 (5.88)
Livestock	19,557 (9.10)	23,950 (7.01)	28,350 (6.74)
Off-farm income	4,200 (1.95)	7,680 (2.25)	8,705 (2.07)
Homestead gardening	1,069 (0.05)	2,077 (0.06)	2,457 (0.05)
Total household income	214,843	341,527	420,846
% contribution of agricultural income to household income	67.30	63.95	64.29
CPI	100	157	220
Real household income	214,843	218,102	191,415

Source: Field surveys (2006, 2012, 2018)

Note: The figures in parentheses indicate percentage (%) share to household income.

Table 6. Comparison of total revenue, agricultural family labor income, agricultural income, off-farm income, and total household income in 2005, 2011, and 2017 (BDT)

Particulars	2005	2011	2017	Kruskal Wallis Statistic
Total gross revenue	333,976	552,313	826,694	
Agricultural income	144,591	218,395	270,564	
Household income	214,843	341,527	420,846	
CPI	100	157	220	
Real gross revenue	333,976	352,713	376,009	0.13
Real agricultural income	144,591	139,469	123,062	0.16
Real household income	214,843	218,102	191,415	0.87

Source: Field surveys (2006, 2012, 2018)

Bangladesh that negated gain in nominal income over time. However, it is encouraging to note that the real income from all sources for *gher* farming household is stable over time. Earlier studies have also found that *gher* farming system has generated more agricultural income as well as household income compared to traditional and MV rice producers in the southwest Bangladesh (Barmon, Kondo, and Osanami 2004b).

CONCLUSIONS AND POLICY IMPLICATIONS

The study evaluated the impacts of joint prawn-rice *gher* farming system in sustaining soil fertility, MV rice productivity, and income of the farmers from Bilpabla village, Khulna district in southwestern Bangladesh covering a 13-year period (2005–2017). Results reveal that the *gher* farming system over the period studied has improved soil quality as seen in the mean MSQI and SDI, thereby indicating the farming system's long-term sustainability. The experiences and perception of farmers point to two causes of improved soil quality: (1) the washing out excessive salts and sulfur from soils during the rainy season, and (2) the additional organic soil nutrients from leftover feeds and the decomposition of naturally grown aquatic ferns (azolla) and algae. Although

MV rice productivity in the prawn-rice *gher* farming system of the sampled farmers has fluctuated over the years from 2005 to 2017, it is still significantly higher than the traditional year-round MV rice cultivation practiced in Bangladesh. The prawn-rice *gher* farming system has had significant impact on both agricultural income and total household income. Real income remained stable over time as nominal income significantly increased, implying that the *gher* farmers have been able to offset the effects of high inflation. All told, the prawn-rice *gher* farming system appears sustainable over the long run as it enabled farmers to stabilize their real income and enhanced soil quality of rice-fields, which helped keep MV rice productivity in the *gher* system higher than the conventional MV rice farming system over time. The study's results point to the need for research on developing varieties of MV rice that are specifically suited to the *gher* farming system, to capitalize on the improved soil fertility that results from the system. It is also important to pursue the development of commercial feeds and markets for prawn, which is the main income generating component of the joint prawn-carp-rice enterprise. This would further the future growth of agriculture and boost the incomes of *gher* farmers in the southwestern region of Bangladesh.

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