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Sustainable Integrated Agricultural Farming System in Bangladesh : An Empirical Evidence of Rice-Prawn *Gher* Farming System

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Summary

The present paper attempts to examine the long-run impacts of rice-prawn *gher* (RPG) farming system on household income, soil fertility status, environment and ecology considering the issue of sustainable integrated agricultural farming. Two sets of primary data, namely socio-economic data of RPG farming and soil fertility data of the own plots of selected RPG farmers were used in this study. Twenty RPG farmers who belong to 30 *gher* plots in 2006 were randomly selected from Bilpabla village of Khulna district. Socio-economic data of prawn and modern variety (MV) rice production were collected through comprehensive questionnaire in 2006. At the same time soil samples were collected from these mentioned 30 plots at the beginning and at the end of MV paddy production and were tested in SRDS laboratory in Dhaka. The same gher plots have been surveyed again in 2012. The study found that the RPG farming has increased agricultural income approximately by 1.76 times and household income by 1.22 times over the study period. However, the nutrient components of soil have remained the same. The RPG farmers use very small amount of chemical fertilizer for MV paddy production, however, per hectare yield is also same in 2006 and 2012, but significantly higher than year-round MV (YRMV) paddy production in other villages in Khulna district. The RPG farming has positive impact on environment; even though, it has meager negative impacts on ecology. Therefore, it may be concluded that the RPG farming is technically feasible, economically viable, socially acceptable and environment-friendly.

1. Introduction :

Rice-prawn *gher* (RGP) farming is an indigenous technology combining aquaculture and agriculture developed and used by local farmers in Southwestern Bangladesh since mid 1980s. The term" rice-prawn gher "refers to a modification of paddy field that has been used for prawn and modern variety (MV) paddy cultivation. The mid field (locally known as *chatal*) of *gher* is surrounded by high wide dikes and canals that lies in the periphery of the dikes. The whole land of *gher* is filled up with rainwater from June to December and resembles to a pond and is used to cultivate prawn (*Macrobrachium rosenbergii*) and carp fishes. The entire land becomes dry naturally from January to April except canals. The canals retain sufficient water for MV boro paddy during this time.

Prior to the RPG farming, the Southwest region experienced a period of severe environmental change during 1960s and 1980s because of the construction of embankments and polders that resulted permanent water logging and increased saline intrusion causing adverse impact on the production of agricultural crops (Kendrick, 1994). After the adoption of RPG farming system, the cropping patterns have changed thus permitting the farmers to produce prawn and modern varieties (MV) of paddy throughout the year.

Only a handful of studies focus on the impacts of RPG farming on labor demand (Barmon et al. 2004a) and household income (Barmon et al. 2004b; 2004c and 2004d), and the impact of shrimp gher farming on the environment (Asaduzamman

et al. 1998; Aftabuzzaman, 1998; Nijera Kori 1996; Bhattacharya et al. 1999; Rahman 1998; and Islam 2003) and ecology (Datta, 2001; Islam, 2001) in the coastal region in Bangladesh. Some studies also focus sporadically on input use in MV paddy production under rice prawn gher farming (Barmon et al. 2008), economic evaluation on soil fertility for MV paddy production under RPG farming (Barmon, et al. 2007 and 2010), water productivity for MV paddy production (Barmon et al. 2008), history, present and future challenges of RPG farming (Ahmed et al. 2008a; 2008b; 2008c; and Barmon et al.,2005), women's participation in gher farming (Barmon et al. 2007) and child labor participation in prawn fry collection (Ahmed, et al. 2009), diversified economies and efficiencies in a" blue-green revolution " (Rahman and Barmon 2010, Ahmed et al. 2010), *gher* revolution (Kendrick, 1994), livelihood analysis of prawn farmers and associated groups (Ahmed et al. 2008c), economic returns to prawn and shrimp farming (Islam et al.2005), agrarian change and economic transformation (Ito 2002, 2004), and prawn and shrimp marketing (Ahmed et al. 2009; Islam 2008) and energy productivity and efficiency of the RPG system (Rahman and Barmon, 2012). Ahmed et. al. (2008a and 2009) and Chowdhury, et al. (2006) qualitatively discussed the sustainability of RPG farming system in Southwest Bangladesh. The RPG farming has already been experienced more than 25 years. However, the components of sustainable farming system under RPG farming have not been analyzed explicitly. Therefore, the present study estimates the components of sustainable farming system (economic, social, soil fertility status, environmental and ecological status) under RPG farming in Bangladesh.

2. Conceptual Framework of the Study

Sustainable land management or sustainable farming system combines technologies, policies and activities aimed at integrating socioeconomic principles with environmental concerns in order to (i) maintain or enhance production/services (ii) reduce the level of production risk (iii) protect the potential of natural resources and prevent degradation of soil and water quality (iv) be economically viable and (v) be socially acceptable (Dumanski, 1993). Farmers of many developed and developing countries have been adopted different types of technologically advanced agricultural systems since the period of green revolution. Some of them were locally developed considering local weather, production atmosphere, and availability of inputs in the production process. Some of them had prescribed agricultural technology developed by international organizations. Some farming systems are being sustained in long run simply because these are technically feasible, economically viable, socially acceptable, and ecological and environment-friendly. However, some farming systems are not being sustained due to ecological and environmental drawbacks.

RPG is an agriculturally advanced farming system in the Southwestern Bangladesh. Prawn and shrimp, fish and MV paddies are being produced under this farming system. The present study examines whether the locally adopted RPG farming is sustainable farming system considering that it is technically feasible, economically viable, socially acceptable, environment-friendly, consistent with household endowments, and relevant to the needs of farmers. Besides, RPG farming is well spread considering as food security and risk resilience, environmentally compatible, economically viable, and socially acceptable. The present study considers the process of long-term agricultural development from the aspects of chemical fertilizers use and land productivity.

3. Methodology of the Study

Two sets of data — socioeconomic and soil fertility status of rice and prawn production data were used to justify sustainable land management or farming system. Socioeconomic data of rice and prawn production were collected through comprehensive questionnaire and samples of soil were tes-

ted in the laboratory. Twenty farmers belonged to 30 farm plots were randomly selected from Bilpabla village. Soil samples were collected from the mentioned 30 *gher* plots before and after modern varieties (MV) of paddy production. The Bilpabla village was selected wittingly; because the villagers have vast experience on RPG farming system like other parts of Khulna district and they directly or indirectly depend on their daily livelihood in various *gher*-farming activities. The farm survey was carried out during the month of October 2007 and October 2012 based on the agricultural cropping year 2006 and 2011, respectively.

3.1 Description of the study area

The present study was conducted in Bilpabla village, which is located in about 7 km west from headquarter of Khulna district, and about 310 km south from the capital Dhaka. Bilpabla village was selected purposively because it is one of the typical villages in RPG farming. The demographic characteristics of the village are very similar to other villages where RPG farming is being practiced.

The climate of the study area is tropical monsoon-type with wide seasonal variations in rainfall; moderately warm temperatures with high humidity. The rainy season is from June to October when the monsoon air stream sweeps in from the Bay of Bengal and Bangladesh receives heavy rainfall ranging from 1,937 to 2,949 mm in 2001 (BBS, 2011). Khulna district annually receives, on an average, 1,696 mm of rain varying from 1,159 mm to 1,994 mm. The average monthly humidity was 77%, which varies between 61% (March) and 84% (August) in 2001. However, the average monthly humidity was 79% ranging between 66% (March) and 87% (July). The mean temperature was 27℃ in 2010 (BBS, 2011).

3.2 Soil sampling

In order to assess the impact of RPG farming system on soil quality of MV paddy fields, the soil samples were collected at the beginning of paddy transplanting and at the harvesting time of paddy. Each sample of soil is a well mixture of nine subsamples those were collected from nine different places of a particular farm plot. The soils were taken from 0～15 cm depth, which represent the cultivated topsoil (BARC, 1997). The sample soils then placed in polythene bags and well dried by natural sunshine, which were again placed in polythene and leveled numerically and sealed for transportation to the laboratory for testing. Since the present study conducts to explore the impact of RPG farming on soil quality (fertility), therefore, the samples as well as plots number were identified with same numerical value at beginning of paddy transplanting and at the harvesting times of MV paddy cultivation.

3.3 Soil and analytical methods

Soils were dried in air, grounded, and sieved with 0.5 mm mesh. Some soil chemical properties were analyzed by routine methods; briefly, pH (H_2O, 1:2.5), pH(KCl, 1:2.5), EC (1:5), total carbon and nitrogen by the combustion method (C-N analyzer, Sumigraph NC-1000), exchangeable cautions extracted with ammonium acetate, phosphorus absorption coefficient, available P by the Troug method, hot-water extractable NH_4-N and B, available zinc and cupper extracted with 0.1 mol/L HCl and easily reducible Mn.

4. Results and Discussions

4.1 Economic Impacts of Rice-prawn *Gher* Farming System

The components of sustainable development theory are discussed based on the locally developed RPG farming system in this section.

4.1.1 Analysis of Costs and Returns of rice-prawn gher farming

Cost, return, profit, and agricultural income as well as household income of rice-prawn gher farmers are discussed in this section. The cost items in *gher* farming includes prawn and carp fish finger-

lings cost, various kinds of feed cost, labor, medicine, watching house cost, seed/seedling cost of paddy and vegetables, land preparation cost (bullock), irrigation, pesticides and fertilizer costs. On the return side, gross return includes revenue from prawn, fish, paddy and vegetables. The calculation procedure of variable cost, fixed cost, labor cost, gross revenue, net profit and agricultural income are stated below.

4.1.2 Variable Costs

Variable costs, which consists the largest share of total cost of RPG farming include prawn and carp fingerling costs, feed cost, medicine cost, and all labor cost (family labor, permanent and temporary hired labor) for the prawn and fish production. It also includes seedlings cost of paddy and vegetables, land preparation cost, irrigation, pesticides and fertilizer costs and labor cost for paddy and vegetables production. The variable costs of prawn and MV paddy production are presented in table 1. All variable costs (input costs) of prawn production under RPG farming in 2006 (for the average gher farm of size 0.83 hectare) was Tk 117,222 and Tk 294,478 in 2012, indicating the input costs has increased about 2.5 times in 2012 compared to 2005. The main reason is that all input costs have significantly increased (mainly prawn fingerling and feed costs) over the period. Similarly the input costs of MV paddy production under RPG farming have also increased by approximately 1.83 times in 2011 compared to 2005 mainly because of higher inputs price.

4.1.3 Fixed Costs

The fixed costs of *gher* farming are considered as maintenance cost of *gher* farming, preparation cost of monitoring house, depreciation cost of construction of *gher* farming, and land rent. The land rent is considered as the amount paid by the tenant farmer to the landlord. In case of own farmers, the land rent is calculated on the basis of the present value of land rent that the own farmers could have earn by renting out their land. The components of fixed costs are also presented in table 1. It shows that total fixed cost remain unchanged over the study periods. The main reason is that the socio-economic status of RPG farmers has upgraded simply because of the profit of *gher* farming. As a result, the family labors are interested to work in his owned *gher* plots. Now they hire labor for maintaining and repairing dikes and uprooting grass on and sides of *gher* plots. Even though, per unit rent of *gher*

Table 1. Production costs and returns of rice-prawn gher (RPG) farming

Particulars	(2005)	(2011)	Ratio
A. Variable costs of prawn and fish production:	(Taka)	(Taka)	
(i) Prawn fingerlings	42,238	103,800	2.46
(ii) Carp fish fingerlings	1,785	19,500	10.92
(iii) Feed	42,281	143,583	3.40
(iv) Medicine	11,904	2,608	0.22
(v) (a) Permanent hired labor	5,870	6,010	1.02
(b) Temporary hired labor (male)	9,906	16,989	1.72
(c) Temporary hired labor (female)	3,238	1,988	0.61
Sub total	117,222	294,478	2.51
B. Variable costs of paddy and vegetables production:			
(i) Paddy seed/seedlings	1,262	1,710	1.35
(ii) Vegetables seed/seedlings	453	850	1.88
(iii) Land preparation (bullock)	1,189	1,550	1.30
(iv) (a) Temporary hired labor (male)	4,848	9,945	2.05
(b) Temporary hired labor (female)	806	3,031	3.76
(v) Irrigation	1,308	1,805	1.38
(vi) Pesticides	1,062	1,090	1.03
(vii) Fertilizer	732	1,338	1.83
(viii) Machinary cost	470	890	1.89
Sub Total	12,130	22,209	1.83
C. Total variable costs (A+B)	129,352	316,687	2.45
D. Fixed costs:			
(i) Depreciation cost of gher preparation	1,197	1,460	1.22
(ii) Monitoring housing:			
(a) Maintenance/repairing	770	1,480	1.92
(b) Depreciation cost	256	867	3.39
(iii) Opportunity cost of land	10,013	15,543	1.55
(iv) Opportunity cost (family labor-male and female)	21,422	13,218	0.62
(v) Land rent	14,288	16,756	1.17
Total fixed costs	47,946	49,324	1.03
E. Total costs (variable and fixed costs) (C+D)	177,298	366,011	2.06
F. Revenue from prawn and fish:			
(i) Prawn	231,451	363,070	1.57
(ii) Carp fish	20,088	69,685	3.47
G. Revenue from paddy and vegetables:			
(iii) Paddy	20,933	45,663	2.18
(iv) By-product of paddy	2,798	5,720	2.04
(v) Vegetables	3,813	7,636	2.00
H. Total revenue (F+G)	279,083	491,774	1.76
I. Net profit (H-E)	101,785	125,763	1.24

Source: Field Survey, 2006, 2012.

Notes: (i) 1US$=83.60 Taka, May, 2012.
(ii) Surveyed average gher farm size was 0.83 hectare.
(iii) Sample size was 20.

plots become double in 2012 the amount of rent in total fixed cost remains very small.

4.1.4 Labor Cost

Labor cost, which is the main cost items in *gher* farming, includes cost of family labor, permanent and temporary hired labors. The family labor cost is calculated on the basis of opportunity cost. The hired labor cost is simply the local agricultural wage. Most of the labor cost is incurred in harvesting of prawn and cleaning the *gher*. The labor costs of prawn and MV paddy production are presented in table 1. The wage rate of temporary and permanent hired labor for male and female both for prawn and MV paddy production has increased significantly in 2012 compared to 2006. The wage rate for hired male labor was Tk 120/day in 2006 whereas it increased to Tk 250/day in 2012.

4.1.5 Analysis of Gross Revenue, Net Profit and Agricultural Income

Gross revenue is calculated by multiplying the total volume of production of the farm by the farmgate price. Net profit is calculated by subtracting total production cost (fixed and variable costs) from gross revenue. Total agricultural income of the *gher* farmer who cultivated their own *gher* plots includes net profit of *gher* farming, opportuni ty cost of family labor and land cost, while the *gher* farmers who rented in the *gher* plots from the landlords includes net profit of *gher* farming and opportunity cost of family labor for rented farmer. Total revenue and net profit of RPG farming are shown in table 1. The table shows that total revenue of prawn and MV rice was Tk. 279,083 annually in 2006 whereas it was Tk. 490,774, indicating that the revenue has increased about 1.76 times in 2011 compared to 2005. The amount of profit of prawn and MV paddy production was Tk. 101,786 in 2005 and Tk. 125,763 annually in 2011, which indicates that the profit also increased about 1.24 times than 2005.

4.1.6 Analysis of Household Income of Gher Farmers

In general, there are three main sources of income of agricultural households in developing countries. These are profit from agricultural production, agricultural labor income, and non-agricultural activities. The agricultural profit is the sum of crop income, and income from livestock and poultry. Similarly, agricultural labor income includes both family labor used on own farm and labor sold to other farms, and 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 sources of household income are presented in table 2. It is evident that agricultural income remains the principal source of income for households in the sampled gher farmers, which have increased considerably over the sampled period. Annually total household income of RPG farmers has increased from Tk. 164,647 in 2005 to Tk. 201,642 in 2011. 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 for *gher* farmers. The agricultural wage accounts only 9 percent for *gher* farmers,

Table 2. Household income of rice-prawn *gher* farmers

Sources of income (Taka)	2005	2011	Ratio
(i) Profit/agricultural income	101,785	125,763	1.24
(ii) Opportunity cost of family labors			
(a) Male	19,616	6,583	0.34
(b) Female	1,806	6,635	3.67
(iii) Opportunity cost of land	10,013	15,543	1.55
(iv) Agricultural wage (male)	11,358	20,122	1.77
(v) Agricultural wage (female)	3,951	4,502	1.14
(vi) Livestock	2,443	4,650	1.90
(vii) Off-farm income	12,359	15,830	1.28
(viii) Homestead gardening	1,316	2,014	1.53
Total household income	164,647	201,642	1.22

Source: Field survey, 2006, 2012.

indicating that the family members enjoyed more leisure time and engaged in other off-farm activities.

Annual per household income in rural areas in Bangladesh was Tk 11,577 in 2010 (BBS, 2010). Table 2 shows that the total household income for gher farmers was Tk 164,647 in 2005, indicating that per household income of gher farmers was nearly two times higher than that of Bangladesh. Therefore, it can be concluded that the gher farming technology has increased household income in this area compared to other rural areas in Bangladesh.

4.1.7 Comparison of Income

It has found that the farmers in *gher* farming in the study area have gained their agricultural income as well as household income. In this section, an attempt is made to determine the income gain from *gher* farming system by comparing to two cropping year 2005 and 2011.

Total gross revenue, agricultural family labors 'income, off-farm income, total agricultural income and household income of *gher* farmers in cropping years 2005 and 2012 and their ratios in table 3. It is evident from the table 3 that total gross revenue of *gher* farmers in 2011 was 1.76 times higher than 2005. However, the agricultural family labor income of the *gher* farmers was considerably smaller in 2011 compared to 2005, indicating that the RPG farmers have earned a large amount of profit from *gher* farming, as a result, now they are enjoying more leisure time that was not possible at the beginning of the *gher* farming. The agricultural income and family off-farm income have increased evenly compared to 2005. Therefore, it can be concluded from the table that RPG farmer has generated more agricultural income as well as household income in 2011 compared to 2005. Besides, earlier studies found that gher-farming system has generated more agricultural income as well as household income compared to traditional and modern variety (MV) paddy in the southwest Bangladesh (Barmon et al, 2004a, 2004b).

Table 3. Comparison of total revenue, agrcultural family labor income, agricultural income, off-farm income and total household income in 2005 and 2011

Particulars	2005	2011	Ratio
(i) Total gross revenue	279,083	491,774	1.76
(ii) Agricultural family labor income	21,422	13,218	0.62
(iii) Agricultural income	101,785	125,763	1.24
(iv) Off-farm income	12,359	15,830	1.28
(v) Household income	164,647	201,642	1.22

Source: Field survey, 2006, 2012.

5. Impacts on Soil Nutrients

5.1 Physical and Chemical Properties of Soils

The chemical and physical properties of soils in RPG and YRMV paddy farming are presented in table 4.

Soil pH

The term pH refers to alkalinity or acidity of a growing media water solution. Soil pH and base saturation are the important chemical properties that influence soil nutrient availability and plant growth and the activities of soil microorganisms and organic matter decomposition. All plants are not able to tolerate acidic or alkaline soils. Rice crops usually prefer slightly low acidic soils compared to other crops. On an average, the mean soil pH in rice field in RPG farming system at the beginning of transplanting and at the harvesting time of paddy cultivation was 6.69 and 7.05, respectively in 2005. However, the corresponding figures become 6.06 and 6.33 respectively in 2011. The implication of the result is that the mid-paddy field of *gher* plots is washed during rainy season when prawn is cultured. As a result, the natural salt has not been accumulated in paddy field like shrimp farming.

Electrical Conductivity (EC)

Electrical conductivity (EC) is an important soil property related to salinity, and is often used for delineating other soil properties. EC measures the amount of total dissolved salts or irons inthe water. It appears

from table 4 that the mean value of EC were 6.45 ds/m and 4.87 ds/m at the beginning (December), and at the end of harvesting (April), respectively, in MV paddy production under RPG farming system in 2005, while the corresponding figures becomes 5.42 ds/m and 3.92 ds/m in 2011. The implication of the result is that under RPG farming system, the mid paddy fields are washed out at the beginning of transplanting due to prawn production. On the other hand, at the end of paddy harvesting, the EC value has increased, which indicates that the salts have accumulated along with production in both farming systems. Thus it can be concluded that even though the salts accumulate in paddy fields in RPG farming system, after prawn production the paddy field escape from salinity problem.

Total Nitrogen

Nitrogen, a major component of proteins, hormones, chlorophyll, vitamins and enzymes is essential for plant life. The availability of optimal nitrogen for crop production influences the crop yields and deficiencies reduce yields. The total nitrogen (%) content was 0.46 and 0.37 in the soils of paddy fields of RPG farming at the beginning and at the end of harvesting, respectively, in 2005; while the corresponding figures become 0.52 and 0.33 in 2011. The implication is that the leaf over feed and algae enhance the nitrogen that helps to reduce nitrogen (urea) application of MV paddy production.

Organic Matter

Organic matter that affects soil ŝ structure, water storage capacity and nutrient supply is considered as the most important indicator of soil quality and productivity. On an average, the total organic matter (OM) in the soils of paddy field in RPG farming system at the beginning and at the end of harvesting were 13.16 and 10.32, respectively, in 2005; while the corresponding figures in 2011 were 11.17 and 7.75. This indicates that over the year OM percent in RPG farming has decreased very small amount that may not be harmful to MV paddy production. It has found that this OM (%) has decreased more rapidly in year-round MV paddy farming that hinders the optimum MV paddy production in Bangladesh.

Table 4. Descriptive statistics of soil fertility status (0-15cm) in rice-prawn *gher* farming system in Bilpabla village, Khulna district

	Before rice production (2005)				After rice production (2005)				Before rice production (2011)				After rice production (2011)			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
pH	7.69	0.746	5.00	9.10	7.05	0.424	6.2	7.9	6.06	0.60	4.80	7.30	6.33	0.40	5.80	7.90
EC (ds/m)	6.45	1.75	3.65	10.45	4.87	1.43	3.12	7.43	5.42	2.08	1.44	11.71	3.92	1.14	1.98	6.78
Total Nitrogen (%)	0.46	0.118	0.29	0.75	0.37	0.102	0.19	0.61	0.52	0.11	0.32	0.74	0.33	0.13	0.06	0.64
Organic matter (%)	13.16	3.24	7.87	16.13	10.32	2.97	4.65	15.43	11.17	2.52	6.39	14.79	7.75	2.82	1.21	12.71
	mg/100g soil								mg/100g soil							
Potash (K)	1.25	0.403	0.62	2.89	0.97	0.23	0.61	1.60	0.85	0.43	0.32	1.98	1.04	0.56	0.17	2.64
Calcium (Ca)	29.9	6.41	16.25	49.05	23.23	4.33	14.75	32.75	32.4	5.61	18.2	45.31	26.13	4.56	17.41	34.13
	µg/g soil								µg/g soil							
Phosphorus (P)	12.23	7.73	2.26	37.00	9.56	5.89	2.16	34.00	6.65	3.63	2.30	19.40	7.02	2.99	2.30	16.10
Zinc (Zn)	2.17	1.09	0.80	6.8	1.59	0.937	0.60	5.82	1.45	0.60	0.24	3.40	1.12	0.54	0.36	3.34
Sulpher (S)	232.5	95.1	49.1	410.6	176.20	80.4	49.1	381.6	307.7	156.2	78.0	729.1	166.9	96.1	11.4	444.5
Manganese (Mn)	108.48	38.2	39.4	212.0	88.24	22.5	50.00	173.6	105.5	40.2	34.6	198.7	94.5	17.43	63.5	188.5
Boron (B)	2.87	0.655	1.75	4.23	2.05	0.549	1.12	3.51	1.59	0.48	0.29	2.23	1.37	0.61	0.23	2.52
Copper (Cu)	12.54	3.71	5.42	21.81	10.64	2.11	4.42	14.42	10.6	4.23	8.67	20.45	8.23	1.67	6.76	16.5
	g/kg								g/kg							
Total Nitrogen (N)	5.57	1.9	2.4	9.5	5.44	2.05	2	9.5	6.3	2.21	5.43	7.12	5.55	1.43	5.23	6.83
Total Carbon (C)	71.1	30.25	31	144	72.27	30.73	22	144	78.9	13.65	65.23	83.2	44.13	15.9	39.2	55.7
	Ratio								Ratio							
C/N ratio	12.517	1.214	11	15	13.067	1.015	11	15	13.12	2.65	9.54	14.87	11.2	1.97	9.54	12.9

Source: Laboratory experiement, 2006 and 2012.

Notes: 1) Soil sample size was 30 from 20 *gher* farmers.

2) SD indicates standard deviation.

Carbon Nitrogen (C/N) Ratio

Carbon Nitrogen (C/N) ratio of soils was almost same at the beginning of paddy transplanting and at the harvesting of paddy in RPG farming system in 2005 and 2011. The C/N ratio was comparatively higher in the soils in RPG farming system at the end of the harvesting in 2005 and at the beginning at the paddy production in 2011 of YRMV paddy farming system. This indicates that the RPG farming system has significant impacts on the soil fertility for MV paddy production.

Available Phosphorus

Phosphorus is essential for plant growth, seed germination, photosynthesis, protein formation and metabolism in plants and flower and fruit formation. Deficiency symptoms are purple stems and leaves, maturity and growth retardation, premature drops and poor yields of fruits and flowers. The Phosphorus content has decreased significantly after paddy production in 2005 and 2011.

Calcium (Ca), Zinc (Zn), Sulpher (S), Manganise (Mn), Cupper (Cu) and Boron (B)

The nutrient of Ca, Zn, S, Mn, Cu, and B are also most the same at the beginning and the end of paddy production in 2005 and 2011 under RPG farming system. This indicates that the RPG farming system maintains the soil nutrients status over the study period. The main reason is that farmers apply various types of feeds during prawn and fish production in rainy season, and the leftover feeds make the soil fertile for MV paddy production that was not possible for MV paddy production for year round MV paddy production in Bangladesh (Barmon, 2010).

6. Impacts of Prawn Farming

The RPG system has also significant impacts on environment and ecology like shrimp *gher* farming system in Bangladesh (Kendrick, 1994; Kori, 1996; Ansary, 2000; Abedin et al. 2000; Islam et al 2001; and Toufique 2002). The impacts of RPG farming system on environments and ecology have been discussed in this section.

6.1 Impacts on Environments and Ecology

The RPG farming system has negative impacts on ecology and livestock. Fish diversity and fish catches has decreased in the swamplands, canals and rivers, because of siltation or blockage of fish migration route, water pollution as well as decreased swampland area due to *gher* construction (Abedin at et, 2000; and Islam, 2001). Besides some of the indigenous fish, tortoise and frogs are disappearing gradually and some varieties have already become extinct due to over fishing of Post Larvae (Islam et. al. 2001).

The main input of prawn production-mud snail has direct significant negative impacts on ecology and human health. People have collected mud snails (*Pila globosa*) intensively from swamplands, canals and river to use as feed for prawn production; as a result, the mud snail has already disappeared in greater Khulna district forcing the farmer importing mud snail from other districts as well as India. This unplanned intensive harvest of mud snail has negative impacts on ecology (Kendrick, 1994; Chowdhury, 1999; Datta, 2001; and Islam, 2001). Dutta (2001) as mud snails play an important role in wetland ecosystem and soil chemistry. Williams and Khan (2001) mentioned that the women and children who crush the mud snail for prawn feed suffer from skin irritations and respiratory complaints. In addition, the farmers often dump the shell of mud snails at the edge of roads or in nearby canals thereby polluting the local waterway and sometimes blocking the natural drainage system. However, recently this shell is being used as an input of poultry feed and lime. The grinding process of the shells creates a great deal of dust that also causes respiratory problems for human health because the grinding mills are mainly located in residential areas (Barmon, 2006).

6.2 Impacts of Rice-prawn Gher Farming on Livestock

The impact of RPG farming on livestock is ambiguous. Kendrick (1994), Williams and Islam (1999)

and Williams and Khan (2001) argued that livestock has decreased mainly due to the loss of grazing land and unavailability of fodder crops. However, Barmon et al. (2003) concluded that this farming system has a positive impact on livestock. Livestock and poultry have increased compared to shrimp *gher* farming. Before RPG farming had started, landlords or rich farmers had a large number of cows and buffaloes but most of the small, landless and marginal landowners had no cows or some-times a few in numbers. But now a day, people are rearing more than two to three cows for milk and cow-dung. Instead of unavailable grazing fields, the *gher* farm owners 'even landless farmers collect feed (grasses) from embankments and store by-product of paddy (straw) for cattle feed on gher embankments. The farmers usually use stored straw in the rainy season when fodder is not available.

6.3 Impacts on Landholding Patterns and Land Tenurial System

The shrimp farming system has also significant impacts on landholding patterns and land tenurial system in the southwest Bangladesh. Marginal and small farmers have forced to sell their farmland with very cheap land value. Sometimes the politician and financially strong farmers captured the nearby other farmers 'small plots without any payments or giving very small amount of money as a land rent. Consequently, the small and marginal farmers are abolishing from agricultural sectors mainly due to the introduction of shrimp farming owned or controlled by so called politicians and large farmers. A large number of small and marginal farmers have already migrated to other places for employments and better livelihood (Field survey, 2005).

The RPG farming system has major impacts on institutional change in land tenurial arrangement from traditional sharecropping to fixed rent system. The rice-prawn gher farming system is a capital-intensive enterprise and needs proper management for optimal production to protect virus disease as well as poaching of prawns. Moreover, the landlords and the tenants cannot predict the main output before harvesting. As a result, the land tenurial arrangement has converted from traditional sharecropping system to fixed rent system. The land rent depends on the land productivity, distance from river, and altitude level. The land rent has increased over the year because of large participant of marginal and landless farmers as well as profitable enterprise comparing to paddy farming.

The landlords mainly engage in non-farm activities and a small portion of their total gher farm operates mainly for home consumptions using permanent hired labor. Even though the rice prawn gher farming is a profitable enterprise, landlords do not operate total gher farm because the permanent hired labor disrupt prawn production at every step. As a result, the landlords rented out gher farms to marginal and landless farmers on fixed rent agreement basis.

The rice-prawn gher farming system has redistributed the landholding patterns due to the participation of marginal and landless farmers. Some marginal and landless farmers became small landowners after the successful operation of rice prawn gher farming (Barmon, 2006).

7. Impacts on groundwater for irrigations

7.1 Irrigation system for paddy production under RPG farming system

The canals of RPG farming system maintain sufficient water for irrigation of MV paddy production. The paddy fields of RPG farming are irrigated from canal using indigenous handmade tools such as *doone* and swing basket. The rich farmers having large area of *gher* farming irrigate paddy fields using shallow tubewell. Recently, farmers make new canals inside the *gher* plots and filled up the old canals using the soil of new canals. This transformation and moving of soils make the soil more fertile for optimal MV paddy as well as prawn production.

7.2 Sources of water input and irrigation tools

The MV paddy yield varies on the availability of water along with optimal application of chemical fertilizers and pesticides. Water of canals in *gher* plots and ground water and/or river water are the main source of MV paddy production in RPG farming and YRMV paddy farming in the Southwestern Bangladesh. As farmers in RPG farming, irrigate the paddy fields from canals of *gher* plots, usually indigenous homemade tools such as *doone* and swing baskets are used for irrigation. Moreover, shallow tubewell is also used to irrigate from canals for large-scale paddy fields of *gher*. On the other hand, deep and shallow tube well is the main irrigation tool for MV paddy production in YRMV farming.

7.3 Water use efficiency in MV paddy production

The physical structure of RPG farming allows each *gher* plot to dig several canals to retain sufficient water during MV *boro* paddy production. The farmers in RPG farming divide the mid field into several plots based on the uniformity of altitude level. When the farmers irrigate the paddy fields from own canals, excess water go to the canals through outflow and leakage from ridge of paddy fields.

On the other hand, usually farmers in YRMV farming irrigate the paddy field collectively using common canals. Therefore the quantity of irrigation water varies widely at the head and tail side depending on the location of the paddy field. The extent of wastage of water is lesser if the paddy field is in the proximity of the water source and vice versa. But farmers in RPG farming use frequently excess outflow and leakage water from the canals of own *gher* plots that is not possible for MV *boro* production in YRMV paddy production. Therefore, it can be concluded that the efficiency of water use in MV *boro* paddy production is relatively higher in RPG farming than YRMV paddy farming in the southwestern Bangladesh.

8. Impacts on domestic food and protein supply

The RPG has significant impact on domestic food and protein supply in the study village. In RPG farming, prawn is the main exportable item while MV paddy, fish and vegetables that produced on the dike are mainly the family consumption items. Almost all farmers rear cows, duck and poultry in the home-yard. Straw is the main feed items of milking cow and bullocks. Consequently households of RPG farming are getting vegetables from own *gher* dike, fish from *gher* pond and milk and eggs from rearing cows and poultry. Thus, it can be concluded that the RPG farming is supplying domestic food and protein to family members of gher farmers.

9. Analysis of MV Paddy Yield

The actual yield (kg/ha) of MV paddy production under RPG in 2005 and 2011 is presented in table 5. The table reveals that on an average, the actual yield of MV paddy in RPG farming system is almost the same in both cropping year 2005 and 2011, indicating that per hectare MV paddy production remain unchanged during the cropping year 2005 and 2011. Thus it may be concluded that RPG farming may be sustainable in long run if the present production environment prevail in the study area.

Table 5. Actual yield (kg/ha) of MV paddy in RPG farming system in 2005 and 2011

Farming system	Mean	SD	Min	Max
Year 2005	4,685	688	3,753	6,123
Year 2011	4,720	398	3,759	5,399

Sources: Field survey, 2006, 2012.
Note: Sample size 20.

10. Analysis of Sustainable RPG Farming

All the components of sustainable integrated farming system are found in RPG farming system in southwest Bangladesh and portrayed in figure 1. The present study analyzes the economic and non-economic measurements for the sustainability of RPG farming. In economic measurement, the RPG farming has increased agricultural income, household income, created higher labor demand for male and female and increased adequate food and

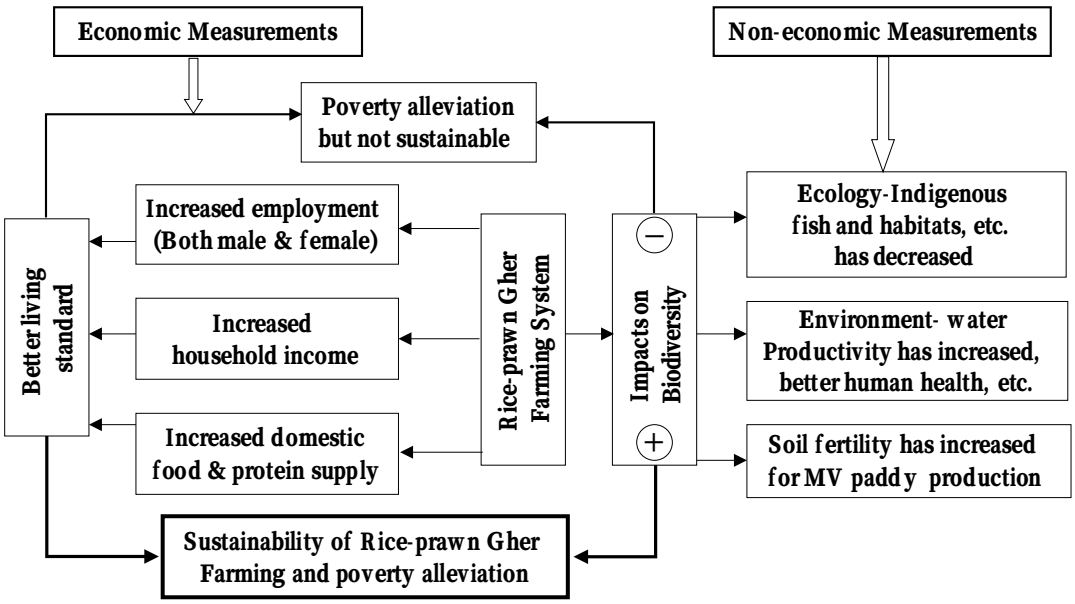

Fig 1: Flow diagram of sustainability of rice-prawn *gher* (RPG) farming system and poverty alleviation in Bangladesh

protein supply for the local community as well as family consumption. The RPG farming provides sufficient paddy and fish from own *gher* farm and milk from rearing cows in home-yard. Thus reducing poverty and ensuring food security to the study area in Khulna district.

Non-economic measurement includes mainly environment and ecological impacts on the biodiversity as well as locality. The RPG farming is environment-friendly rather than rice-shrimp in the southwest Bangladesh. As shown earlier, the RPG farming has significant impact on soil fertility that enhances the MV paddy yield over the year. In RPG farming system, the farmers use comparatively less chemical fertilizers for MV paddy production that was not possible in year-round MV paddy production in Bangladesh. However, the RPG farming has inconsequential negative ecological impact on biodiversity in the locality.

8. Conclusions and Policy Implications

RPG farming system, locally known, as "*White Revolution*" is an indigenous technology solely developed by local farmers since the mid 1980s and emerged as a profitable business in southwestern Bangladesh. The study found that the yield of MV *boro* paddy is higher in RPG farming system compared to YRMV *boro* and *aman* paddy production. This results more agricultural income (more than five times higher) as well as household income (more than double) from RPG farming, compared with YRMV *boro* and *aman* paddy production in Bangladesh. The household income per capita in the RPG farming area is almost double to that of the YRMV paddy farming area, and about four times higher than that of the people in rural Bangladesh. Therefore, it can be concluded that the RPG farming system has created a good production environment for MV paddy farming. This farming system has also created employment opportunities both for hired and family labor, thus given new fabric in the dynamics of the rural economy.

RPG farming has significant impacts on soil quality and land productivity compared to YRMV paddy farming system in Bangladesh. The main reason is that the paddy fields under RPG farmingare washed out every year during prawn produc-

tion. The leftover feeds of prawn production provide a significant amount of soil nutrients such as nitrogen, soil organic matter, phosphorus, potassium and other nutrients to soils in fields for MV paddy under RPG farming system. As a result, farmers in RPG farming use comparatively less chemical fertilizer for MV paddy production compared to YRMV paddy farming. Some farmers do not apply chemical fertilizer at all in paddy fields in MV production even though the per hectare yield is almost similar to the other RPG farmers indicating that the soil quality as well as soil fertility has improved due to the leftover feeds of prawn. Therefore, it can be concluded that the RPG farming system has significant impacts on soil quality and increased land productivity.

RPG farming has significant impacts on water productivity for MV *boro* paddy production compared to YRMV paddy farming. Water input also used efficiently in RPG farming than YRMV farming. Unproductive water runoff and/or water outflows are very small during irrigation in RPG farming than YRMV paddy farming. Moreover, large-scale water is required for soaking of land preparation for paddy transplanting in YRMV paddy farming. As ground water is used in MV paddy production, the paddy fields were affected by salinity. Preserved water that comes from rainfall and flooding in rainy season, used in MV paddy production in RPG farming system. Therefore, it could be concluded that RPG farming has significant impacts on water utilization and MV paddy yield in compared to YRMV paddy farming in southwestern Bangladesh.

Therefore based on empirical evidence it can be concluded that the locally adopted RPG farming is sustainable farming system or at least not to check the components of sustainable farming system such as technically feasible, economically viable, socially acceptable, environment-friendly, consistent with household endowments, and relevant to the needs of farmers.

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