Rice-prawn Farming System: Impacts on Soil Quality and Land Productivity of Modern Variety Paddy Production in Bangladesh

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ABSTRACT

The rice-prawn gher (RPG) farming system, locally known as the White Revolution, is an advanced, indigenous agricultural technology solely developed by local farmers in southwestern Bangladesh in the mid-1980s.

This paper examined the impact of RPG farming on soil quality and land productivity of paddy production of modern varieties (MV) in Bangladesh. Two contrasting farming systems — RPG and year-round modern varieties (YRMV) — were considered. A total of 40 farmers (20 farmers from RPG and 20 from YRMV paddy farming) were randomly selected. Each of the sampled 20 RPG and 20 YRMV paddy farmers owned 30 farm plots. Soil sample collection procedures were conducted in two phases — at the beginning of paddy transplanting and during harvesting — in both farming systems.

RPG farming has significant impacts on soil quality and land productivity in Bangladesh. The findings indicate that the leftover feeds of prawn production provide a significant amount of soil nutrients, such as nitrogen, soil organic matter, phosphorus, potassium, to soils in fields for paddy production under the RPG farming system. As a result, RPG farmers use comparatively less chemical fertilizers per unit of MV paddy production compared to YRMV farmers. Moreover, per unit yield of MV paddy was higher in RPG farming than in YRMV paddy farming.

INTRODUCTION

The rice-prawn gher (RPG) farming system is an indigenous agricultural technology solely developed by farmers in the mid-1980s. The early stage of shrimp and prawn practice was centered in Bagerhat in the greater Khulna district because of waterlogging and soil saline intrusion. As a result, paddy production was hampered because of excessive saline in paddy fields (Kendrick 1994).

RPG farming is an advanced agricultural technology locally known as the White Revolution (prawn is "white gold"). The cropping pattern that farmers had been using since the Green Revolution changed when the RPG farming system was introduced. Prior to RPG, farmers practiced year-round modern varieties (YRMV) of paddy farming. Commercial shrimp and prawn farming spread and increased rapidly in the last two decades in southwestern Bangladesh due to high international market demand and the tendency for quick money-making (Deb 1998) as well as high agricultural income (Barmon et al. 2004a; 2004b; 2004c). However, the transformation of paddy fields to shrimp and prawn farming has changed the land use patterns in the densely populated coastal areas in tropical Asia and Latin America (Dewalt et al. 1996; Gujja and Finger-Stich 1996; Flaherty et al. 1999) and led to negative impacts on the environment and ecology (Deb 1998; Dewalt et al. 1996; Flaherty et al. 1999; Ali 2004) The shrimp-rice farming system is different from the RPG farming system in terms of feeding method, management, and production environment (i.e., brackish water is needed for shrimp culture, whereas freshwater is needed for prawn production in Bangladesh). As such, these farming systems have different impacts on soil quality in paddy fields; which in turn, affect paddy production.

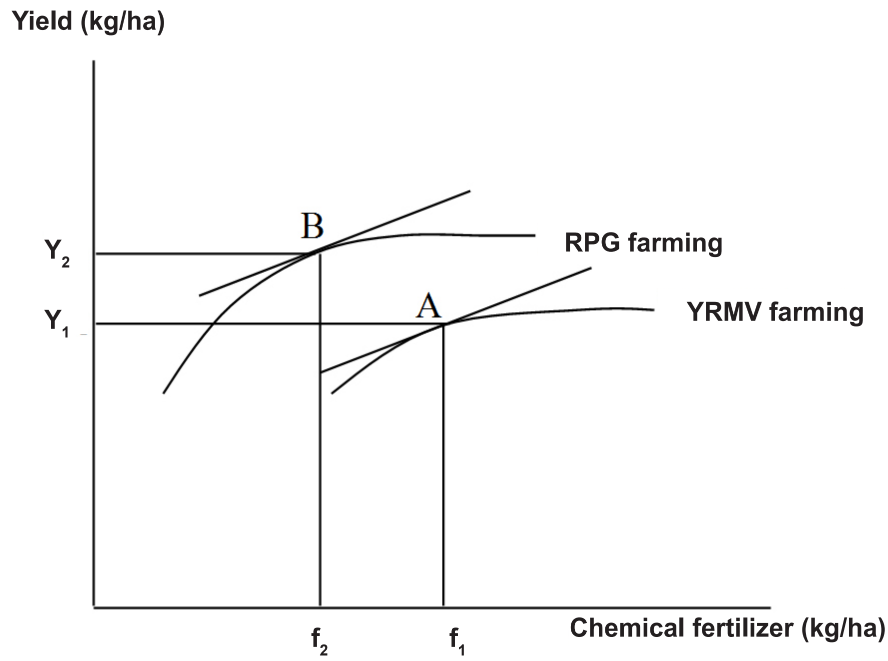
In Bangladesh, a number of studies on soil quality in various aspects of agricultural farming have been conducted. Clearing and deforestation of land in Gazipur and Chittagong districts have significantly reduced the soil nutrients (Islam and Weil 2000; Islam et al. 1999). Prolonged shrimp farming has rapidly diminished soil quality in rice fields and reduced paddy production. In other words, the soil quality of paddy fields has degraded significantly after the introduction of shrimp farming in southwest Bangladesh (Ali 2004; 2006). However, the impact of the RPG farming system on soil quality and land productivity has been given less attention. Thus, this study attempts to examine the impact of RPG farming on soil quality and land productivity of modern variety (MV) paddy production in Bangladesh.

CONCEPTUAL FRAMEWORK

RPG and YRMV are two advanced agricultural farming systems—through which modern paddy varieties are produced in southwestern Bangladesh. The present study considers the impacts of agricultural-technology changes on chemical fertilizer use in MV paddy production as well as land productivity. In addition, it examines the impact of the Green Revolution and the White Revolution on soil quality and land productivity in MV paddy production in Bangladesh. The RPG farming system aimed to improve crop yield using less input, especially fertilizers and labor. This paper compares only the application of chemical fertilizers for MV paddy production between the two farming systems. The hypothetical yield curves of two existing MV paddy production systems (RPG and YRMV) in Bangladesh are depicted in Figure 1.

Figure 1 shows that the yield curve of the RPG farming system shifts upward from YRMV mainly because of agricultural technological progress. With the advent of an advanced RPG farming system, farmers could produce more paddy grain per unit of farm land compared

Figure 1. Hypothetical yield curves of MV paddy under rice-prawn gher (RPG) and year-round modern variety (YRMV) farming systems in Bangladesh



to YRMV using the same amount of chemical fertilizers. The main reason is that farmers apply various combinations of feeds into gher plots during prawn production although the prawns do not eat the supplied feeds properly. Therefore, it can be assumed that the leftover feeds and feces of prawn and fish make the soil fertile and reduce the application of chemical fertilizers in the RPG farming system.

In the YRMV farming system, Y_1 amount of paddy could be produced using f_1 amount of fertilizer, whereas Y_2 amount of paddy can be produced using f_2 amount of fertilizer under RPG farming. One of the most popular MV varieties, BR28, as well as other varieties with similar yiels to that of BR28, were being produced in the study villages during the study period. Thus, it is assumed that the yield of the varieties is almost the same at the best production environments in the study villages.

THE RICE-PRAWN GHER FARMING SYSTEM IN BANGLADESH

In Bangladesh, two types of gher farming are being operated: brackish water-based shrimp-MV paddy farming and freshwater-based RPG farming. Shrimp-MV paddy farming is large in size and scale (area), and needs saline water. RPG farming is comparatively small in size and scale, and utilizes fresh water.

The term “rice-prawn gher” refers to a modification of paddy field that has been used for prawn and paddy cultivation. The main land—locally known as *chatal*—of the gher is surrounded by high and wide dikes, as well as canals that lie in the periphery of the dikes (Figure 2). The whole area of the gher is filled with rainwater from June to December and resembles a pond during those months. In this period, farmers cultivate prawn (*Macrobrachium* *rosenbergii*) and carp. The entire area, with the exception of canals, becomes naturally dry from January to April. The canals retain sufficient water for MV *boro* paddy during this time. As a result, farmers can grow MV *boro* paddy on the *chatal*. Moreover, farmers grow vegetables on the dikes throughout the year. Some farmers grow vine-type vegetables up trellises inside the gher.

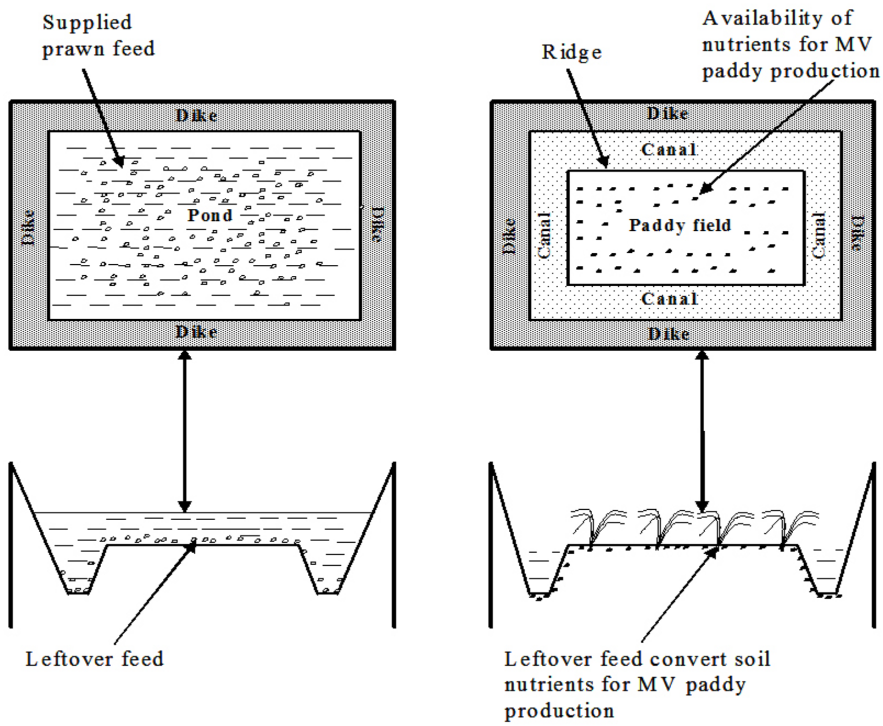
Irrigation System for Paddy Production in the RPG Farming System

As mentioned, the canals in the RPG farming system retain sufficient water for irrigating MV paddy. These fields are irrigated from canals using indigenous handmade tools, such as indigenous homemade irrigation tool (*doone)* and basket. The rich farmers who employ RPG farming in large areas also irrigate their paddy fields using shallow tubewells. Recently, farmers have made new canals inside the gher plots and filled the old canals using the soil of new ones. The transformation and moving of soils enhance soil fertility for optimal MV paddy and prawn production. Farmers think that if the position of canals shifts alternately every three to four years, the soil becomes more fertile for crop production.

Irrigation Water Input in YRMV Paddy Farming

As mentioned earlier, MV *boro* and MV *aman* paddies are produced throughout the year—MV *boro* paddy is produced from January

Figure 2. Diagram of rice-prawn gher farming system and the soil fertility process for MV paddy production



a) Gher farming in rainy season
b) Gher farming in winter season

to April while MV *aman* paddy is produced from June to December. Irrigation is required for MV *boro* paddy production, and farmers mainly irrigate the paddy field with groundwater using deep and shallow tubewells.

MV *aman* is a rainfed crop that is produced during the rainy season in Bangladesh. Usually, no irrigation is required to cultivate MV *aman* paddy in the study villages. Sometimes, minimal irrigation is required (depending on the amount of rainfall) and farmers irrigate the paddy fields using both deep and shallow tubewells.

Plowing Input of MV Paddy Production in the Two Farming Systems

Typically, paddy fields are plowed two to three times with a power-tiller, bullock, or tractor before transplanting is done. In YRMV paddy farming, farmland is plowed by tractor after *boro* paddy is harvested, and by power-tiller before transplanting MV *aman* paddy.

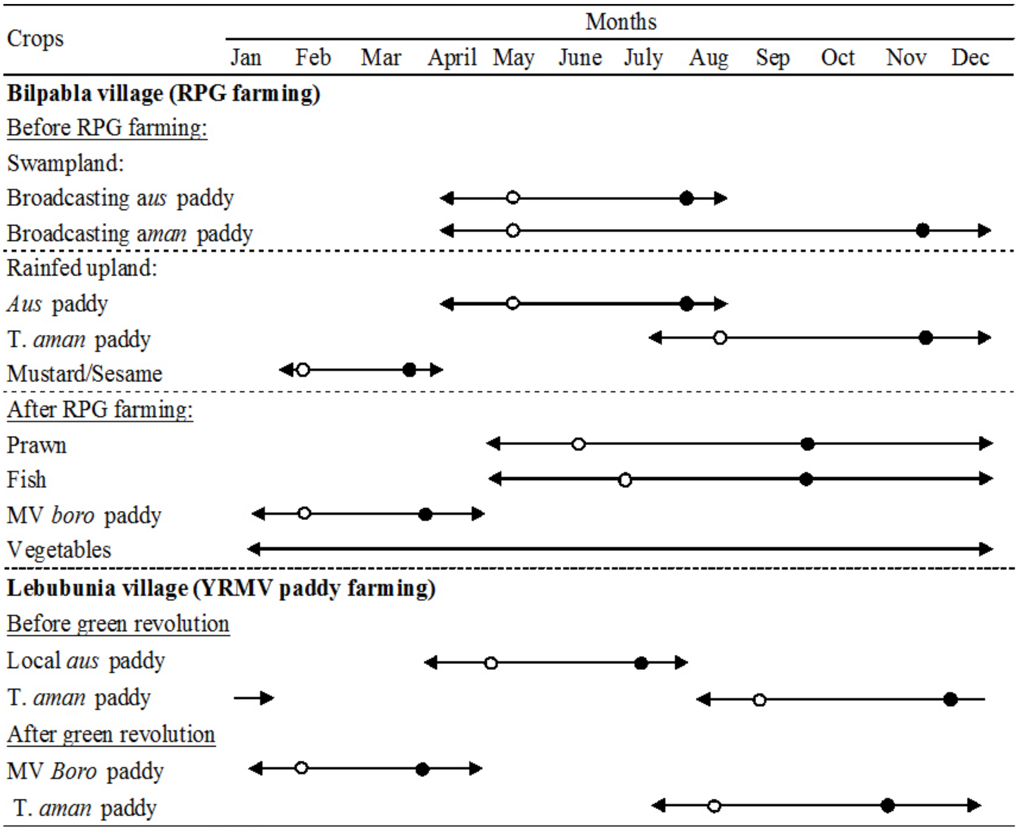
On the other hand, paddy fields in the RPG farming system are plowed after paddy is harvested because the fields (central field of gher farming) are not dry enough for plowing or they sometimes retain small amounts of water suitable for planting. Moreover, soil in the central fields becomes clay-like because these soils are mixed well during prawn harvesting. However, a small number of paddy fields at comparatively high altitudes and near roadsides are also plowed before transplanting because the paddy fields are dry enough after prawn harvesting.

CROPPING PATTERNS OF THE STUDY VILLAGES

The cropping patterns of the study villages are presented in Figure 3. Prior to the advent of RPG farming in Bilpabla village, the farmers cultivated only local *aus*; broadcasting *aus* and *aman* paddy in swamplands and transplanting *aman* (T. aman) paddy in the upper lands. The broadcasting of *aus* and *aman* paddy types have almost disappeared mainly because of siltation of inland rivers and canals, embankments of rivers, and environmental changes. Oil seed crops, such as mustard and sesame, were also produced in the comparatively high-altitude land located in the riverside. The life cycle of broadcast *aman* is longer than the broadcast *aus* paddy, though the sowing time is the same for both. The sowing time of *aus* and *aman* paddy is in April/May, while harvesting time is in August for broadcast *aus* and December for broadcast *aman*. Farmer sow *aus* and *aman* seeds together in April/May because after June/July, the whole area is underwater due to heavy rain, making it impossible to transplant *aman*. This production system of combining local *aus* and floating *aman* paddy together is locally known as *domuti.*

RPG farming has changed the cropping patterns dramatically in the study area because its construction has created opportunities for crop diversification. Along with prawn and fish, farmers can now cultivate MV *boro* paddy in the mid-field, and vegetables for home consumption in the dikes of the gher. Prior to RPG farming, farmers cultivate oil seeds, such as rape, mustard, and sesame, after the harvest of local broadcast *aman* paddy since they are not able to cultivate these due to the physical construction of RPG canals and dikes. RPG farming system has increased vegetable production compared to past harvests. The farmers have also planted fruit trees (coconut, mango, guava, jackfruit, banana, and papaya, to name a few) in the dikes. The production period of prawn and fish starts from May/June to December/January, MV *boro* paddy from the end of January to end of April, and vegetables throughout the year.

Figure 3. Cropping patterns of the study villages



Source: Field survey, 2006
Notes: ○ indicates the period up until the sowing paddy, and release of prawn fish is carried out
● indicates start of harvesting time
T. *aman* indicates transplante *aman* paddy

METHODOLOGY

Description of the Study Villages

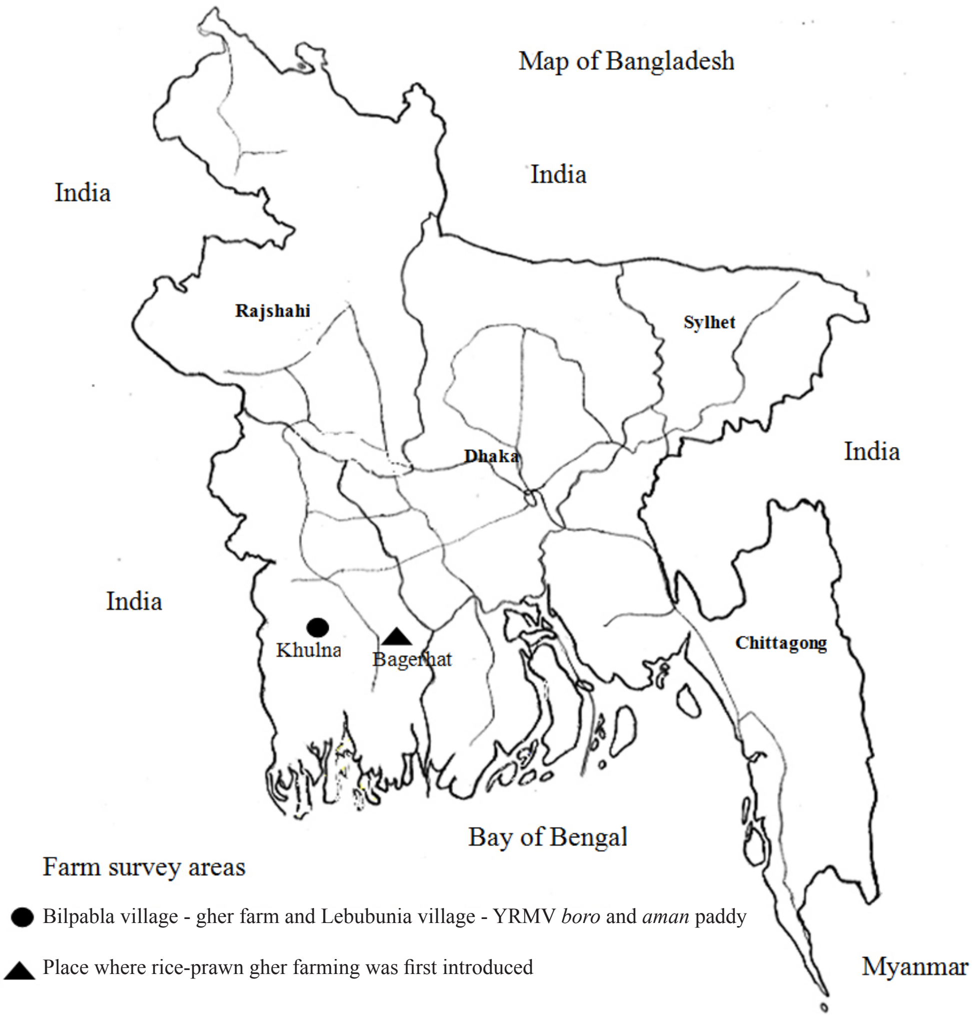
The research was conducted in Bilpabla and Lebubunia villages, which are located about 7 and 5 kilometers (km) west from the headquarters of the Khulna district, respectively, and about 310 km south of the capital Dhaka (Figure 4).

Bilpabla village was selected because it is one of the typical villages in RPG farming. The prawn-producing environment/factors (such as water quality, weather, rainfall, temperature, and soil quality) of Bilpabla are very similar to other villages where RPG farming is being practiced.

Lebubunia village was selected because its cropping pattern is similar to Bilpabla prior to RPG farming. Moreover, Lebubunia and Bilpabla are neighboring villages. The altitude of rice fields in Lebubunia is slightly higher than those used for RPG farming in Bilpabla. As a result, farmers in Lebubunia village could not convert their paddy field into gher farms. The farmers in Lebubunia village mainly grow YRMV paddy twice a year.

The climate of the study area is tropical monsoon-type with wide seasonal variations in rainfall, moderately warm temperatures, and

Figure 4. Study area



high humidity. The rainy season formally starts in June and continues until October, when the monsoon air stream sweeps in from the Bay of Bengal. During this time, Bangladesh receives heavy rainfall and most places receive more than 2,538 millimeters (mm). In 2001, rainfall was between 1,937 to 2,949 mm (BBS 2005). The Khulna district annually receives, on average, 1,696 mm with a wide range of 1,159 to 1,994 mm. In 2005, the average monthly humidity was 77 percent, which ranged between 61 percent (March) and 84 percent (August). In 2006, the average monthly humidity was 79 percent, ranging between 66 percent (March) and 87 percent (July). The mean temperature was 27^0C in 2005 (BBS 2005).

Soil Sampling

To assess the impact of the RPG farming system on soil quality of MV paddy fields, soil samples were taken from RPG and YRMV paddy farms. A total of 40 farmers (20 farmers from RPG and 20 from YRMV) were randomly selected from two study villages. Each of the sampled 20 RPG and YRMV paddy farmers owned 30 farm plots.

Soil sample collection procedures were conducted in two phases. The first phase was conducted at the beginning of paddy transplanting (26-29 December 2005 in Bilpabla and 30-31 December 2005 in Lebubunia) and at harvest time (22 April 2006 in Bilpabla and 27 April 2006 in Lebubunia).

Each soil sample was a mixture of nine sub-samples that were collected from nine different places in a particular farm plot. The soils were taken from a depth of 0-15 centimeters (cm), which represented the cultivated topsoil. After collecting soils, the sample soils were placed in polythene bags and sun-dried. After drying, the soil samples were again placed in polythene, labeled numerically and sealed for transportation to the laboratory for testing. As the study aimed to explore the impact of RPG farming on soil quality (fertility), the samples as well as plot numbers were identified using the same numerical value at the beginning of paddy transplanting and during harvesting .

Soil and Analytical Methods

Soils were air-dried, ground, and sieved with 0.5 mm mesh. Some soil chemical properties were analyzed by routine methods: H_2O 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 cations extracted with ammonium acetate, phosphorus absorption coefficient, available P by the Troug method, hot-water extractable NH_4-N and B, available zinc and copper extracted with 0.1 mol/L HCl, and easily reducible Mn.

RESULTS AND DISCUSSION

Physical and Chemical Soil Properties

The chemical and physical properties of soils in RPG and YRMV paddy farming are presented in Table 1.

Soil pH

The term "pH" refers to the alkalinity or acidity of a growing media water solution. Soil pH and base saturation are the important chemical properties that influence soil nutrient availability, plant growth, the activities of soil microorganisms, and organic matter decomposition. Most field crops prefer neutral or slightly acidic soil because it promotes the solubility of micro and macro nutrients for plant growth and development. Rice crops usually prefer slightly low acidic soils compared to other crops. On the average, the mean soil pH in rice fields at the beginning of transplanting and during harvesting of paddy cultivation in the RPG farming system was 6.6 and 6.0, respectively. On the other hand, the mean pH in paddy fields during the same periods in the YRMV system was 6.5 and 7.1, respectively. The mean pH decreased after paddy production in RPG farming, whereas it increased in YRMV paddy farming.

Electrical conductivity

Electrical conductivity (EC) is an important soil property related to salinity and often used for delineating other soil properties. EC measures the amount of total dissolved salts or the total amount of dissolved ions in the water. The mean values of EC at the beginning and end of MV production in Bilpabla and Lebubunia villages are shown in Table 1.

Table 1. Some chemical and physical properties of soils in Bilpabla and Lebubunia villages

Properties of Soil			Bilpabla Dec 2005	Bilpabla Apr 2006	Lebubunia Dec 2005	Lebubunia Apr 2006	t_1 statistic	t_2 statistic
pH (H_2O)			6.6	6.0	6.5	7.1	4.25*	-5.76*
pH (KCl)			5.9	5.5	5.8	6.5	3.66*	-2.78*
ΔpH			-0.8	-0.5	-0.7	-0.6		
EC		(mS/m)	71.0	161.0	159.0	143.0	-8.65*	3.82*
Total C		(g/kg)	78.0	78.0	21.0	19.0	0.75	3.12*
Total N		(g/kg)	6.1	5.9.0	2.0	1.7	1.99**	4.23*
C/N ratio			13	13.0	10.0	11.0	0.65	1.89***
Exchangeable cation	Ca^{++}	($cmol_c$/kg)	43.0	39.0	25.0	24.0	2.12*	1.87***
	Mg^{++}		12.0	11.0	10.0	9.0	1.56	1.24
	K^+		0.9	0.7	0.8	0.7	2.14*	1.18
	Na^+		3.8	5.3	3.4	4.6	5.23*	3.27*
CEC		($cmol_c$/kg)	50.0	52.0	31.0	30.0	2.56*	1.45
Base saturation		(%)	121.0	110.0	137.0	129.0	2.65*	3.12*
Cation ratio	Ca/Mg		3.5	3.4	2.6	2.8	1.23	-1.87***
[based cmol]	Mg/K		14.0	18.0	13.0	12.0	-2.44*	3.23*
	Ca/K		49.0	62.0	34.0	33.0	-4.24*	1.50
Available P (Troug)	(mg P/kg)		83.0	70.0	75.0	86.0	3.45*	-2.31*
PAC	(g P/kg)		6.5	6.4	4.4	4.2	2.11*	1.97**
0.1 N HCl	Zn	(mg/kg)	2.7	3.1	2.7	2.3	-2.43*	3.88*
	Cu		1.2	1.5	7.3	6.2	-3.12*	2.86*
Hot H_2O ext. NH_4-N		(mg/kg)	120.0	75.0	61.0	54.0	5.65*	3.76*
Easily reducible Mn		(mg/kg)	72.0	57.0	72.0	74.0	4.33*	-2.21*
Hot water ext. B		(mg/kg)	3.3	2.7	2.1	2.2	3.33*	-0.98
Appar. specific gravity		(g/cm^3)	1.00	1.03	1.10	1.09	1.32	0.87

Abbreviations: EC – electro conductivity
CEC – cation exchange capacity
PAC – phosphorous absorption coefficient

Notes:
t_1 indicates *t*-statistic of soil quality in December 2005 and April 2006 in Bilpabla village
t_2 indicates *t*-statistic of soil quality in December 2005 and April 2006 in Lebubunia village
*, **, and *** indicate statistically significant at 1%, 5%, and 10% level, respectively

The mean value of EC was low (71 Sm/m) at the beginning of MV paddy production (December) in the RPG farming system. Meanwhile, this value more than doubled (159 Sm/m) in YRMV paddy production in Lebubunia village. However, the average value of EC when the paddy was harvested (April) was higher in RPG (161 Sm/m) than YRMV (143 Sm/m). EC increased during harvest in RPG farming because the salts accumulated along with paddy production. Although the salts accumulated in paddy fields, the fields were free from salinity problems after prawn production (rainy season).

Cation exchange capacity (CEC)

Cation exchange capacity (CEC) refers to the amount of positively charged ions in the soil. It is a useful indicator of soil fertility because it shows the soil's ability to retain important plant nutrients, such as calcium (Ca^{++}), magnesium (Mg^{++}), potassium (K^{+}), sodium (Na^{+}), aluminum (Al^{+++}), and ammonium (NH_4^{+}). In general, soil contains more clay and organic matter (OM), which indicates a higher CEC. The CEC of soil in RPG was higher both at transplanting and at harvesting of MV paddy compared to YRMV. This indicates that the soil in the RPG farming system contains more clay and higher OM, and is therefore more fertile.

Total carbon (C)

Soil organic carbon is the biggest part of the soil organic matter (SOM). It is considered the most important indicator of soil quality and productivity as it affects soil structure, water storage capacity, and nutrient supply. On the average, the total organic carbon (C) in the soils of paddy fields in the RPG farming system was almost four times higher than in the YRMV paddy farming system, which also indicates that the soils in the former were more fertile.

Total nitrogen (N)

Nitrogen is a major component of proteins, hormones, chlorophyll, vitamins, and enzymes essential for plant life. It is the most important soil element for crop production. The presence of optimal nitrogen for crop production boosts crop yield while deficiencies reduce yield. The nitrogen content of soils was significantly higher in the soils of RPG paddy fields compared to YRMV paddy fields, which indicates that the soils in the RPG farming system accumulate more nitrogen that enhance land productivity.

Carbon nitrogen (C/N) ratio

Carbon nitrogen (C/N) ratio depends on the total C and N in the soils. In RPG, the C:N ratio of soils was almost the same at the beginning of paddy transplanting and during harvesting. The C:N ratio was comparatively higher in RPG soils than in YRMV, indicating that the former system has significant impacts on soil fertility for MV paddy production.

Available phosphorus (P)

Phosphorus is essential for plant growth. It is also necessary for seed germination, photosynthesis, protein formation, and plant metabolism, as well as flower and fruit formation. Deficiency symptoms are purple stems and leaves, which signal the retardation of maturity and growth. In this case, yields of fruit and flowers are poor and fruits and flowers may drop prematurely. In general, total P content in soil ranges between 200-1500 milligrams (mg) per kilogram (kg). The P content in the study area, which was higher than the general P content level in the soil, decreased significantly after paddy production.

Base saturation

The percentage base saturation (BS%) is termed the proportion of CEC satisfied by basic cations (Ca^{++}, Mg^{++}, K^{+}, and Na^{+}) and it is inversely related to soil acidity. In general, BS% increases when the pH of soil increases. The availability of nutrient cations, such as Ca^{++}, Mg^{++}, and K^{+}, to plants increases with increasing BS% and is usually close to 100 percent in arid-region soils. Base saturation below 100 percent indicates that part of the CEC is occupied by hydrogen and/or aluminum ions. Base saturation above 100 percent indicates that soluble salts or lime may be present, or that there is a procedural problem with the analysis. The BS% of soils in paddy fields in both types of farming systems was above 100 percent at transplanting and at harvesting. However, the BS% was lower in soils in the RPG farming system than in the YRMV paddy farming system, which indicates that more soluble salts existed in the soils of the latter.

Feeds Used in Prawn Production

During the growth period of the prawn, farmers give various types of supplementary feed such as homemade feed, meat of mud snail, and processed feed. The ingredients of homemade feed include oil cakes, polished rice, molasses, wheat bran, wheat, fishmeal, and other feeds in fixed proportions. The meat of mud snails is commonly used as prawn feed, while some farmers also use oil cake, wheat bran, and boiled rice directly.

There is no standard feeding system in the RPG farming system in Bangladesh. The feeding systems, types of feeds as well as quality and quantity of feeds are different from farm to farm, depending on the farmers' experience. At the early stage of the RPG farming system, farmers mainly use meat of mud snails as prawn feed, which are collected from local rivers, ponds, and swamplands. At present, mud snails are unavailable in swampland and rivers, and most of the mud snails are imported from neighboring districts and sometimes from India. Moreover, the price of mud snails has increased significantly due to high demand for prawn feed over the years. As a result, farmers use supplementary feed differently depending on their experience and the practices they employ.

It was observed from the field survey that fishmeal and meat of mud snails are the main complementary feeds of prawn along with beaten rice, legume grain (pulses), oilcakes, wheat bran, and broken rice.

Some farmers also provide fishmeal and meat of mud snails in the gher plots after some interval to observe the availability of feeds and health of the prawn. The sampled farmers did not apply all the feeds that are shown in Table 2 during the 2005-2006 production cycle. Meat of mud snail and fishmeal were ranked highest among the feeds employed in prawn production.

As previously mentioned, farmers use different types of feed in the gher plots during prawn and carp production. However, prawns and carp do not eat all of the supplied feed, which makes the paddy field fertile and the paddy crop subsequently takes the necessary nutrients from the fertile field. After *boro* paddy, the gher is used predominantly for prawn and fish cultivation.

Nutrient Concentrations of Feeds Used in Prawn Production

The nutrient concentrations of feed used in prawn production are presented in Table 3. The present calculation was made based on a per hectare (ha) basis because the study explores how much of the nutrient concentrations come from providing feeds to prawn production in 2005 to 2006. It is noted that farmers usually supply feeds in the mid-paddy field of the gher (*chatal*) instead of canals because the prawns

Table 2. Feed used for prawn production in RPG farming in 2005-2006

Feed Items (kg)	Per Farm	Per Hectare
Starter 1	6.30	8.53
Wheat noodles	12.25	30.05
Fish meal	786.25	1507.57
Beaten rice (Chira)	267.75	586.57
Legume grain	397.50	686.04
Broken rice	146.75	332.40
Oil cake (mustard)	103.75	171.90
Oil cake (soybean)	55.25	55.00
Wheat bran	182.75	430.77
Meat of mud snail	1355.25	2798.15

Notes: 1. Average farm size was about 0.50 ha
2. Sample size was 20
Source: Farm survey, 2006

go there at night to feed. Therefore, the present study considers only the mid paddy field as a measurement of paddy farm area.

Though some supplied feeds move from mid paddy fields to the canals by the feeding nature of the prawn, this is not considered in the present study for simplicity of the calculation. Table 3 shows that the meat of mud snails, fishmeal, and legume grain (pulses) are the main sources of total nitrogen (TN), soil organic carbon (SOC), and available phosphorus (AP), as well as other soil nutrients. The results show that on average, about 257 kg/ha, 64 kg/ha, and 34 kg/ha N; and 1,105 kg/ha, 626 kg/ha, and 307 kg/ha SOC, respectively, came from the meat of mud snails, fishmeal, and legume grain (pulses). Though the amount of leftover feed and nutrients that remains as prawn feces is undetermined, it is believed that a large amount of nutrients accumulate in the mid paddy field, which is not possible in YRMV paddy farming. As a result, the soils in the RPG farming system become more fertile, owing to the leftover feeds of prawn production.

Farmers' Chemical Fertilizer Application in MV Paddy Production

Chemical fertilizers, pesticides, and irrigation are the main necessary inputs for MV paddy production. Land plowing, irrigation system, management, and application of chemical fertilizers are different in RPG and YRMV paddy farming systems. Applied chemical fertilizers are the main enhancers of soil fertility in YRMV paddy farming; whereas along with nutrients from leftover feeds of prawn production, feces of prawn and fish, algae and fungi, and chemical fertilizers are the main sources of soil nutrients in RPG farming. The application of chemical fertilizers in RPG farming depends on the farmers' long-term farm experience and knowledge. After transplanting seedlings in the paddy field, farmers observe the paddy plant frequently. If they think that the growth of paddy plants is going well, they do not apply chemical fertilizers or sometimes use only the required nutrients N, P, and K. It was observed from the field survey that some farmers did not use any chemical fertilizer in MV paddy production.

Table 3. Nutrient concentration (kg) of feed used for prawn production in RPG farming (per ha basis) in the 2005-2006 cycle

Feed Items	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	cr.Si	Na	C
Starter 1	0.44	0.12	0.06	0.34	0.04	0.01	0.0010	0.0010	0.0002	0.30	0.07	3.38
Wheat noodles	0.60	0.03	0.06	0.00	0.00	0.00	0.0003	0.0003	0.0001	0.00	0.00	13.40
Fish meal	64.83	15.08	12.06	33.17	4.52	1.77	0.2400	0.1100	0.0300	55.78	7.95	625.64
Beaten rice (Chira)	8.21	1.17	1.17	0.00	0.59	0.04	0.0100	0.0100	0.0010	1.17	0.03	261.02
Legume grain	33.62	2.74	7.55	1.37	0.69	0.34	0.0300	0.0300	0.0100	2.74	0.10	306.66
Broken rice	6.32	0.66	0.66	0.00	0.33	0.20	0.0100	0.0040	0.0010	1.00	0.00	139.27
Oil cake (mustard)	9.80	1.89	2.92	1.20	0.86	0.25	0.0100	0.0100	0.0002	1.72	0.05	79.07
Oil cake (soybean)	4.18	0.27	1.43	0.27	0.16	0.05	0.0030	0.0040	0.0010	0.27	0.00	24.75
Wheat bran	10.77	8.18	6.03	0.86	4.31	0.37	0.1100	0.0500	0.0030	7.75	0.56	200.31
Meat of mud snail	257.43	11.19	27.98	193.07	19.59	0.59	0.1000	0.3400	0.0500	5.60	6.75	1105.27
Total element content	396.20	41.30	59.90	230.30	31.10	3.60	0.5	0.6	0.1	76.3	15.5	2758.8

Source: Experimental data based on farm survey, 2006

The application of chemical fertilizers in RPG and YRMV paddy farming are presented in Table 4. On average, the farmers in YRMV paddy farming used about 138 kg of nitrogen (N) that ranged from 68 kg per ha to 172 kg per ha, whereas RPG farmers' N application ranged from 0 to 72 kg per ha with an average of only 22 kg per ha. This indicates that, on average, YRMV farmers used about six times more N per ha of BR28 paddy production compared to RPG farmers and 1.2 times more than the potential application dose for BR28 paddy production recommended by the Bangladesh Agricultural Research Institute (BARI). Similarly, more P_2O_5 and K_2O are used in BR28 production in YRMV compared to RPG farming. There is a statistically significant difference ($p < .01$) in the application of N, P_2O_5, and K_2O in BR28 MV paddy between the two farming systems.

ANALYSES OF PADDY YIELD AND LAND PRODUCTIVITY

In this section, an attempt is made to determine the potential yield (kg/ha) of MV BR28 under RPG and YRMV paddy farming systems by comparing it to the potential yield (kg/ha) of MV BR28 paddy production recommended by the Bangladesh Rice Research Institute (BRRI). The recommended potential yield (kg/ha) of MV BR28 paddy is about 5,000 kg/ha (BRRI 2006); however, the optimal yield of BR28 MV paddy varied among the agro-ecological zones in Bangladesh because of soil quality, weather, and rainfall.

Table 5 shows that the actual yield of MV BR28 paddy in RPG farming was significantly higher ($p < .01$) than YRMV farming. Thus, it could be concluded from Table 4 and Table 5 that although RPG farmers used comparatively less chemical fertilizers per ha of BR28 MV *boro* production, their yield was higher compared to that of YRMV farmers. As the yield (kg/ha) of MV BR28 was higher in the RPG farming system than the YRMV paddy farming system, the land productivity of the former was also higher.

THE RELATIONSHIP BETWEEN PADDY GRAIN YIELD (KG/HA) AND APPLIED N (KG/HA)

Among the three main chemical nutrients, nitrogen is the key nutrient that increases paddy production. Only the relationship between grain yields and nitrogen used for MV paddy production in the RPG f and YRMV production systems in 2005 to 2006 was considered (Figure 5).

The figure shows that farmers in YRMV farming used significantly more N (kg/ha) than those in RPG farming ($p < .01$). Some RPG farmers who did not use any nitrogen at all even had higher per ha yield than other RPG farmers, indicating that MV BR28 paddy can be produced under the RPG farming system after an interval of a few years. It may be assumed that farmers provided excessive feeds during prawn production because there is currently no standard measurement of feeds in the RPG farming system in Bangladesh. Again, it may be assumed that if the farmers produce BR28 paddy continuously under RPG farming, then application of soil nutrients that influence the paddy yield will be reduced in future. A similar relationship was found in the case of the applied P_2O_5 and K_2O (kg/ha), and the yield (kg/ha) of MV BR28 paddy production in RPG and YRMV paddy farming systems.

ANALYSIS OF PRODUCTION COSTS AND RETURNS OF MV PADDY PRODUCTION IN RPG AND YRMV PADDY FARMING

The main input costs that are considered for MV paddy production are costs of seed/ seedling, land preparation, irrigation, pesticides, chemical fertilizers, and hired and imputed family labors. Per ha input costs and revenue of

Table 4. Chemical fertilizer use in BR28 production in RPG and YRMV farming systems

Farming System	Chemical Fertilizers (kg/ha)											
	Nitrogen (N)				P_2O_5				K_2O			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
RPG farming	22.2	20.0	00.0	72.7	10.9	14.1	00.0	45.4	6.50	9.8	00.0	29.6
YRMV farming	138.4	25.1	68.1	171.6	54.5	9.1	37.9	79.5	42.10	8.1	31.4	60.6
Potential use	114.0	na	na	na	23.0	na	na	na	84.00	na	na	na
t statistics	-16.20***				-11.59***				-12.59***			

Notes: 1. Urea, TPS, and MP contain 46%, 46%, and 60% of N, P_2O_5, and K_2O in Bangladesh, respectively
2. t statistics show the significant difference between RPG and YRMV paddy farming
3. *** indicates statistically significant at 1% level
4. na indicates data are not available

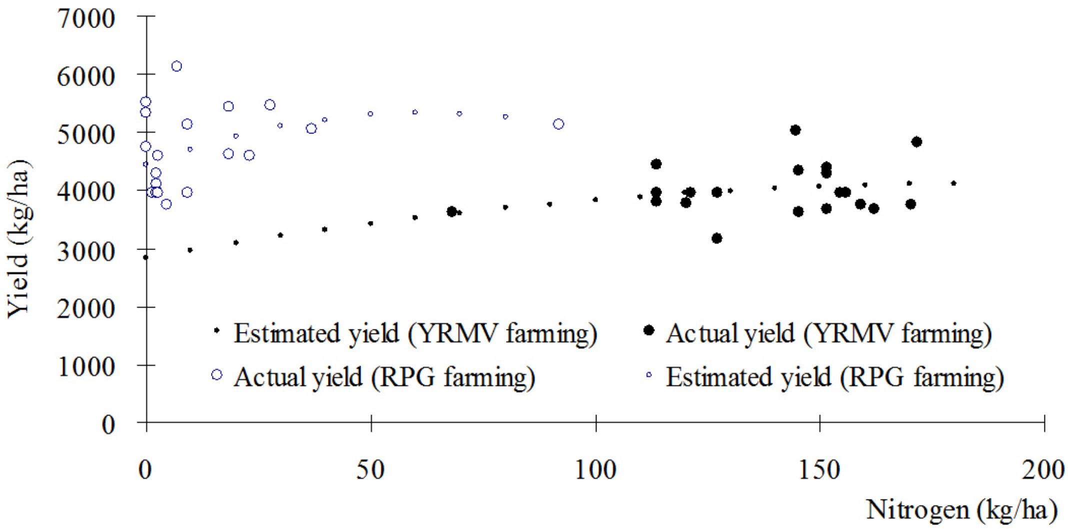
Sources: Field survey, 2006 and BRRI 2006

Table 5. Actual yield (kg/ha) of BR28 MV paddy in RPG and YRMV farming systems

Farming System	Mean	SD	Min	Max
RPG farming (kg/ha)	4,685	688	3,753	6,123
YRMV farming (kg/ha)	3,997	441	3,160	5,028
t statistic	3.76***			

Notes: 1. Potential yield (kg/ha) of MV BR28 paddy is 5,000 kg in Bangladesh (BRRI 2006)
2. * indicates statistically significant at 1% level

Figure 5. Relationship between yield (kg/ha) and nitrogen (kg/ha) application of BR28 production in RPG and YRMV farming systems in 2005-2006



MV paddy production under RPG and YRMV farming systems and *t* statistics are summarized in Table 6.

All input costs per ha of MV paddy production were significantly lower in the RPG than in YRMV ($p < .01$), except the cost of pesticides. Per ha seedling and pesticide costs were almost similar in both farming systems and were not significantly different from each other. It is important to note that the chemical fertilizer cost was about six times higher in YRMV farming than in RPG farming. Usually, the farmers use very small amounts of chemical fertilizers in MV paddy production under the RPG farming system because the leftover feeds of prawn production make the soil fertile.

The irrigation cost was lower in RPG farming mainly because farmers irrigate the paddy fields through the canals of the RPG plot, using mainly handmade tools and low-left pumps. On the other hand, farmers in YRMV farming irrigate the paddy fields by groundwater using deep tube-wells, resulting in higher irrigation costs.

The hired and imputed labor costs, and land preparation costs were also higher in YRMV compared to RPG farming (Barmon et al. 2004). As variable costs of per ha MV production was lower and output was higher in RPG farming, the net return was higher ($p < .01$). Thus, it could be concluded that the RPG farming system has significant impacts on input use in MV paddy production compared to the YRMV paddy farming system.

CONCLUSION

The RPG farming system is an indigenous technology solely developed by local people since the mid 1980s in southwestern Bangladesh. According to previous studies, the Green Revolution that followed, as well as shrimp farming, have degraded soil quality and reduced land productivity in Bangladesh. The findings of this study showed that RPG farming has significant impacts on soil quality and land productivity compared to YRMV paddy farming system in Bangladesh.

Table 6. Per ha input cost and revenue of MV paddy production in RPG and YRMV farming systems

Particulars (Taka)	RPG Farming (A)	YRMV Farming (B)	Ratio (B/A)	t statistics
Seedling cost	1,207	1,587	1.31	-1.42
Land preparation cost	1,616	1,910	1.18	-2.82***
Irrigation cost	1,420	2,564	1.81	-6.96***
Pesticides cost	1,254	1,173	0.94	-0.31
Chemical fertilizer cost	958	6,256	6.53	-25.09***
Hired labor cost	7,586	10,944	1.44	-5.57***
Imputed family labor cost	578	5,547	9.60	-5.23***
Variable costs	**14,619**	**29,981**	**2.05**	**-6.67*** **
Revenue	58,249	49,123	0.84	5.53***
Net return	**43,630**	**19,142**	**0.44**	**8,23*** **

Notes: 1. 1 USD is equal to 69.50 Taka (June 2006).
2. *** indicates statistically significant at 1% level
3. Imputed family labor cost was calculated based on the opportunity cost. The wage rates of male and female labor were Taka 120 and Taka 80, respectively

The results of the soil analysis indicated that soils of paddy fields in the YRMV paddy farming system were more saline, mainly because paddy fields under RPG farming were washed out every year during prawn production. The leftover feeds of prawn production provide a significant amount of soil nutrients, such as nitrogen, soil organic matter, phosphorus, and potassium, to soils in fields in the RPG farming system. As a result, RPG farmers used comparatively less chemical fertilizer per ha of MV paddy production compared to YRMV farmers. Some RPG farmers did not apply chemical fertilizer at all in their paddy fields, though their per ha yield was almost similar to other RPG farmers, also indicating that soil quality and fertility have improved due to the leftover feeds of prawn.

In addition, per ha input costs of irrigation, land preparation, and hired and imputed family labor for MV paddy production were lower. Revenue was higher in the RPG farming system than in YRMV paddy farming ($p < .01$). The pesticide cost was similar in both farming systems. Therefore, the RPG farming system enhanced soil quality, reduced input costs, and increased land productivity compared to YRMV paddy farming system in Bangladesh.

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