Technological Change, Soil Quality and Land Productivity: Evidence from the Rice-prawn Gher Farming System in Bangladesh

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1. Introduction

The rice-prawn gher (RPG) farming system is an indigenous agricultural technology solely developed by farmers in the Bagerhat district since the mid 1980s (Barmon et al [4]). Prior to the RPG farming, paddy production was hampered because of excessive saline in soils of paddy fields (Kendrick, [8]). RPG was an advanced agricultural technology followed by the *Green Revolution* in Bangladesh. The RPG farming is locally known as the *White Revolution* and prawn as the *White Gold*. The cropping pattern was changed after the introduction of the RPG farming system. Prior to the RPG farming, the farmer practiced year-round modern varieties (YRMV) of paddy farming. Commercial shrimp and prawn farming has spread and increased rapidly in the last two decades in southwestern Bangladesh simply due to high international market demand and the tendency for quick money-making (Deb, [6]) as well as high agricultural income (Barmon et al [4]). The shrimp farming has negative impacts on the environment and ecology (Deb, [7]; Ali, [1]). Prolonged shrimp farming has degraded the soil quality in rice fields and reduced paddy production (Ali, [2], [3]). However, the impact of the RPG farming system on soil quality and land productivity has been given less attention. Therefore, the present study attempts to examine the impact of the RPG farming system on soil quality and land productivity of MV paddy production in Bangladesh.

2. Materials and Methods

2.1 Characteristics of the study villages

The present research was conducted in Bilpabla (RPG farming) and Lebubunia (YRMV paddy farming) villages in the Khulna district of southwest Bangladesh. Bilpabla village is one of the typical villages in RPG farming. Prior to the RPG farming system, the cropping pattern of Lebubunia village was similar to that of Bilpabla village, which it neighbors. The altitude level of paddy fields in Lebubunia is slightly higher than RPG farming in Bilpabla village. As a result, the farmers in Lebubunia village could not convert their paddy field into gher farms. The farmers in Lebubunia village mainly grow YRMV paddy throughout the year.

2.2 Soil sampling

In order to assess the impact of RPG farming system on the soil quality of MV paddy fields, soil samples were taken from RPG and YRMV paddy fields. A total of 40 farmers (20 farmers from

RPG and 20 from YRMV paddy farming) were randomly selected from the two study villages. Each of the 20 sampled RPG and YRMV paddy farmers belonged to 30 farm plots. Soil sample collection procedures were conducted in two phases. The first phase was conducted at the beginning of paddy transplanting (December 26-29, 2005 in Bilpabla and December 30-31, 2005 in Lebubunia village) and the second at the harvesting time of paddy cultivation (April 22, 2006 in Bilpabla, and April 27, 2006 in Lebubunia village).

2.3 Soil analytical methods

Soils were dried in air, ground, and sieved with 0.5 mm mesh. Some soil chemical properties were analyzed by routine methods; briefly, p^H (H_2O, 1:2.5), p^H (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, hot-water extractable NH_4-N.

3. Results and Discussions

The present study mainly explains the impacts of RPG farming system on soil fertility and land productivity in terms of (1) salinity problems; (2) inputs cost and revenue (output), and (3) paddy grain yield variability of RPG and YRMV paddy farming system.

3.1 Salinity problems

Among the main indicators of soil salinity, the present study considered only soil p^H, and electrical conductivity (EC). The soil pH and EC of RPG and YRMV paddy farming are presented in table 1.

Table 1. Some chemical and physical properties of soils in RPG and YRMV paddy farming

Properties of soil	Unit	RPG farming		YRMV paddy farming	
		Dec. 2005	Apr. 2006	Dec. 2005	Apr. 2006
pH(H_2O)		6.6	6.0	6.5	7.1
pH(KCl)		5.9	5.5	5.8	6.5
Total C	(g/kg)	78	78	21	19
Total N	(g/kg)	6.1	5.9	2.0	1.7
C/N ratio		13	13	10	11
Electro Conductivity (EC)	(mS/m)	71	161	159	143
Available P (Troug) (mg P/kg)		83	70	75	86
Hot H_2O ext.NH_4-N	(mg/kg)	120	75	61	54

Source: Experimental data, 2007.

Soil pH

The term pH refers to the alkalinity or acidity of a growing media water solution. On average, the mean soil p^H in rice fields in the RPG farming system at the beginning of transplanting and at the harvesting time of paddy cultivation was 6.6 and 6.0, respectively. On the other hand, the mean p^H in paddy field in the YRMV paddy at the beginning of transplanting and harvesting time of paddy cultivation was 6.5 and 7.1, respectively. The mean p^H of RPG farming has decreased after paddy production, whereas, it has increased in YRMV paddy farming after paddy production.

Electrical Conductivity (EC)

Electrical conductivity (EC) is an important soil property related to salinity, and is often used for delineating other soil properties. It appears from the table that the mean value of EC was low

(71 Sm/m) at beginning (December) in MV paddy production under the RPG farming system, whereas this value was more than twice (159 Sm/m) higher in YRMV paddy production in Lebubunia village. However, the average value of EC at the end of paddy harvesting (April) was almost the same for both farming systems.

The results of EC show that the value of EC has increased at the end of paddy harvesting in both farming systems, which implies that the salts have accumulated naturally during the MV paddy production. However, it is interesting that the value of EC is low at the beginning of the paddy transplanting time in the RPG farming system. The main reason is that the mid paddy fields of RPG farming go under water during prawn production time (from May to December). In other words, the mid paddy fields wash out every year during prawn production. Thus it could be concluded that even though the salts accumulate in paddy fields in the RPG farming system, after prawn production the paddy fields escape from the salinity accumulation problem.

3.2 Main components of soil fertility and crop production

Total Carbon (C)

Soil organic carbon is the biggest part of the soil organic matter (SOM) and it is considered perhaps the most important indicator of soil quality and productivity. SOM affects a soil's structure, water storage capacity and nutrient supply. On 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 soil in the RPG farming system was more fertile than in the YRMV paddy farming system.

Total Nitrogen (N)

Nitrogen is the most important soil element for crop production. The availability of optimal nitrogen for crop production influences the crop yields and deficiencies reduce yields. The nitrogen content of soils was also higher (more than three times) in the soils of paddy fields of RPG farming compared to YRMV paddy fields, which indicates that the soil in the RPG farming system accumulate more nitrogen that enhance the land productivity compared to YRMV paddy farming.

4. Analysis of production costs and returns of MV paddy production between RPG and YRMV paddy farming

The main input costs of MV paddy production are considered the costs of seed/seedling, land preparation, irrigation, pesticides, chemical fertilizers, hired and imputed family labors. Per hectare input costs and revenue of MV paddy production under PGR and YRMV farming and t-statistics are summarized in table 2. The table shows that all inputs costs for per ha MV paddy production were lower in the RPG farming system compared to YRMV paddy farming and statistically significant at the 1% level except pesticides cost. Per ha seeding and pesticides costs for MV paddy production were almost identical in both farming systems and they were not significantly different from with each other. The main reason was that the RPG farming system has no significant impacts on seedling and pesticides costs. The most important point is that the chemical fertilizer cost was about six times higher in YRMV farming than in the RPG farming system. Usually the farmers use a very small amount of chemical fertilizers in MV paddy production under the RPG farming system. The main reason is that the leftover feeds of prawn production make the soil fertile as mentioned in the next section. The irrigation cost was lower in the RPG farming system mainly because the farmers irrigate the paddy field from a canal of its own RPG plot. Mainly the farmers use handmade tools and low-left pump for irrigation. On the other hand, farmers in YRMV farming irrigate the paddy fields with groundwater using deep tube-wells. As a result, the irrigation cost is higher in the YRMV than in the RPG farming system. The hired labor and imputed labor costs, and land preparation cost were also higher in YRMV in comparison with the RPG farming system (see details in Barmon et al., [5]). As variable costs of per ha MV production were lower and output was higher in the RPG farming than in the YRMV farming, the net return of MV paddy was higher in the RPG farming system than in the YRMV farming system and this was statistically significant at the 1% level. Thus it could be concluded that the RPG farming system has significant impacts on inputs use in MV paddy production compared to the YRMV paddy farming system.

Table 2. Per hectare input cost and revenue of MV paddy production under RPG and YRMV farming

Particulars	RPG farming (A)	YRMV farming (B)	Ratio (B/A)	t-statistics
Seedling cost (Taka)	1,207	1,587	1.31	-1.42
Land preparation cost (Taka)	1,616	1,910	1.18	-2.82 ***
Irrigation cost (Taka)	1,420	2,564	1.81	-6.96 ***
Pesticide cost (Taka)	1,254	1,173	0.94	-0.31
Chemical fertilizer cost (Taka)	958	6,256	6.53	-25.09 ***
Hired labor cost (Taka)	7,586	10,944	1.44	-5.57 ***
Imputed family labor cost (Taka)	578	5,547	9.60	-5.23 ***
Variable costs (Taka)	**14,619**	**29,981**	**2.05**	-6.67 ***
Revenue (Taka)	58,249	49,123	0.84	5.53 ***
Net return (Taka)	**43,630**	**19,142**	**0.44**	8.23 ***

Source: Field survey, 2006.

Notes: 1) 1 US$ is equal to 69.50 Taka (June, 2006).

2) *** indicates statistical significance at the 1% level.

3) Imputed family labor cost was calculted based on the opportunity cost. The wage rates fc male and female labor were taka 120 and taka 80, respectivily.

5. Farmer's behavior towards chemical fertilizer application in MV paddy production

Prawn/fish (May-December) and MV of paddy (January-April) are being produced throughout the year in the RPG farming system. Usually, chemical fertilizers, pesticides and irrigation are the main necessary inputs for MV paddy production. Land plowing, irrigation system, management and application of chemical fertilizers for MV paddy production are different in the RPG and YRMV paddy farming systems. Applied chemical fertilizers are the main source to enhance the soil fertility for MV paddy production of YRMV paddy farming, whereas, along with nutrients from leftover feeds of prawn production, faeces of prawn and fish, algae and fungi, chemical fertilizers are the main source of soil nutrients for MV paddy production under the RPG farming system. Application of chemical fertilizers for MV paddy production in RPG farming depends on the farmer's long-term farm experience and knowledge. After the transplanting of seedlings in paddy fields, farmers observe the paddy plants frequently. If they think that the growth of paddy plants is good, they do not apply any type of chemical fertilizers to paddy fields or sometimes use only the required nutrients of N, P, and K. It is observed from the field survey that some farmers do not use any type of chemical fertilizers in MV paddy production.

Table 3. Chemical fertilizer use in MV BR28 paddy production in RPG and YRMV paddy farming

Types of farming	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	0	72.7	10.9	14.1	0	45.4	6.5	9.8	0	29.6
YRMV farming	138.4	25.1	68.1	171.6	54.5	9.1	37.9	79.5	42.1	8.1	31.4	60.6
Potential Use	114	na	na	na	23	na	na	na	84	na	na	na
t-statistics	-16.20 ***				-11.59 ***				-12.59 ***			

Source: Field survey, 2006, BRRI 2006.

Notes: 1) Urea, TPS and MP contain 46%, 46% and 60% of N, P_2O_5, and K_2O, respectively, in Bangladesh.

2) t-statistics shows the significant difference between RPG and YRMV paddy farming.

3) *** indicates statistical significance at the 1% level.

4) na indicates data not available.

Application of chemical fertilizers for MV paddy production under RPG and YRMV paddy farming are presented in table 3. The table shows that on average, the farmers in YRMV paddy farming used about 138 kg of nitrogen (N), which varies from 68 kg/ha to 172 kg/ha, whereas the farmers in RPG farming applied only 22kg of N per ha BR28 MV *boro* paddy production, which varies from 0 to 72kg/ha. This indicates that on average, the farmers in YRMV paddy farming used about 6 times more N for ha MV BR28 paddy production compared to RPG farming and 1.2 times more than the potential application dose of BR28 paddy production that was recommended by BARI. Similarly, more P_2O_5 and K_2O are used in BR28 MV paddy production in YRMV paddy farming compared to the RPG farming system. Application of N, P_2O_5 and K_2O in BR28 MV paddy shows statistically significant difference between the two farming system (significant at the 1% level).

6. Analysis of paddy yield and land productivity

In this section, an attempt is made to determine the potential yield (kg/ha) of MV BR28 paddy production under the RPG and YRMV paddy farming system by comparing to the potential yield (kg/ha) of MV BR28 paddy production recommended by Bangladesh Rice Research Institute (BRRI). The recommended potential yield (kg/ha) of MV BR28 paddy is about 5,000 kg (BRRI, [6]). However, the optimal yield of BR28 MV paddy varied among the agro-ecological zones in Bangladesh due to soil quality, weather and rainfall.

Table 4. Actual yield (kg/ha) of BR28 MV paddy between RPG and YRMV paddy 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-statistics	3.76***			

Sources: Field survey, 2006, BARI, 2006.

Notes: 1) Potential yield (kg/ha) of MV BR28 paddy is 5,000 kg in Bangladesh, (BRRI, [6]).

2) *** indicates statistical significance at the 1% level.

Table 4 shows that on average, the actual yield of MV BR28 paddy in the RPG farming system was statistically significantly (at the 1% level) higher than in the YRMV paddy farming system. Thus it could be concluded from table 3 and table 4 that even though the farmers in RPG farming used comparatively less chemical fertilizers per ha BR28 MV *boro* production, the yield was higher in the RPG farming system compared to YRMV paddy farming. As the yield (kg/ha) of MV BR28 was higher in the RPG farming system than in the YRMV paddy farming system, the land productivity is also higher in the RPG farming system than in the YRMV paddy farming system.

7. Relationship between paddy grain yield (kg/ha) and applied N (kg/ha)

Among the main three chemical nutrients, nitrogen is the key nutrient that increases paddy production compared to the other two basic nutrients. Only the relationship between MV paddy grain yields and nitrogen used for MV paddy production under the RPG farming system and YRMV production in 2005/06 was considered and presented in figure 1.

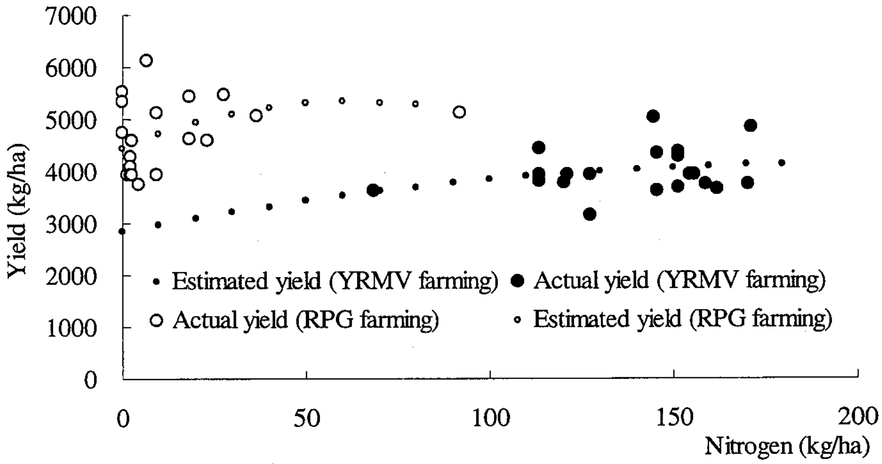

Figure 1. Relationship between yield (kg/ha) and nitrogen (kg/ha) application of MV BR28 paddy production in RPG and YRMV farming systems in 2005-06.

The figure shows that farmers in YRMV farming used more N than that of MV paddy production under the RPG farming system, and nitrogen use (kg/ha) is significantly differrent among the farmers in each farming system. Some farmers did not use any nitrogen at all for MV BR28 paddy production under the RPG farming system, where the per hectare yield was higher compared to other RPG farmers, indicating that MV BR28 paddy could be able to produce under the RPG farming system after a few years' interval. It may be assumed that farmers provided excessive feeds during prawn production because there is no standard measurement yet in the RPG farming system in Bangladesh. Again, it may be assumed that if the farmers produce MV BR28 paddy continuously under the RPG farming system, then available soil nutrients that influence the paddy yield will be reduced in future. A similar relationship was found in case of the applied P_2O_5 and K_2O (kg/ha), and the yield (kg/ha) of MV BR28 paddy production between the RPG and YRMV paddy farming systems.

8. Conclusions

The RPG gher farming system is an indigenous technology solely developed by local people since the mid 1980s in southwestern Bangladesh. The findings of the study showed that RPG farming has significant impacts on soil quality and land productivity compared to the YRMV paddy farming system. The results of the soil analysis indicator EC were that soils of paddy fields of the

YRMV paddy farming were more salinity affected than in the RPG farming. The leftover feed of prawn production provides a significant amount of soil nutrients such as nitrogen, soil organic matter, phosphorus, potassium and other nutrients to soils in the fields for MV paddy production under the RPG farming system. As a result, farmers in RPG farming used comparatively less chemical fertilizer per ha MV paddy production compared to YRMV paddy farming. Some farmers did not apply chemical fertilizer at all in paddy fields in MV production even though the per ha yield was very similar to that of other RPG farmers, which also indicate that the soil quality as well as soil fertility has improved due to the leftover feed from prawn production. In addition, per hectare input costs of irrigation, land preparation, hired and imputed family labor for MV paddy production were lower and revenue was higher in the RPG farming system than YRMV paddy farming and they are statistically significant at the 1% level. The pesticide cost was similar in both farming systems. Therefore, it could be concluded that the RPG farming system has enhanced the soil quality, reduced input cost, and increased land productivity compared to the YRMV paddy farming system in Bangladesh.

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