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Determinants of Sustainable Irrigated and Rainfed Rice Farming in Bangladesh

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ABSTRACT

In Asia, food security and poverty alleviation depends on sustainable rice production. The study examined factors determining irrigated and rainfed rice farming sustainability in Bangladesh. Data for the study were collected through a farm households survey, covering 390 rice growers (sample size was determined by using the Sloven's formula), and also *via* observation, key informant interview, and in-depth informal discussion with relevant stakeholders. Validity of the survey instrument was assessed by experts through contents examination; yet, reliability was estimated by a post-hoc reliability analysis (the Cronbach's alpha coefficient of reliability was 0.86). Based on stepwise multivariate regression analysis, the study found that (i) grower's knowledge, skill, and competency development are common influential factors affecting sustainable rice farming, (ii) the application of resource conservation technology in irrigated rice farming plays a leading role in increasing productivity and preserving natural resources, and (iii) raising land productivity is a decisive determinant for the sustainability of rainfed rice farming. The evidence-based policy implications deduced from the study are outlined.

Keywords: Agri-environment, Resource conservation technology, Human capital, Land productivity, Non-farm income.

INTRODUCTION

All over the world, particularly in Asia, food security and poverty alleviation depends largely on the sustainability of food crop production (Roy *et al.*, 2014). Rice is the staple food for more than half of the world's population. Rice farming is a vital source of livelihood and economic development of billions of people in Asia, where approximately 90% of rice is produced and consumed (Hossain, 2005). Bangladesh is predominantly an agro-based country, and rice is the main crop. It provides 95% of the total food grain production and consumption per annum, employs about 65% of the country's labor force, and contributes to 10% GDP (BARC, 2011). With the introduction of High Yielding Varieties (HYV) and technological progress, rice production has increased remarkably over three decades. However, it raises several concerns of negative environmental impacts from intensification and extensification of rice cultivation. Moreover, increasing population pressure, rapid urbanization and industrialization, climate change, and pervasive hunger and poverty in rice growing areas exacerbate the problem.

In Asia, rain-fed lowland and irrigated systems account for about 90% of rice cultivation (IRRI, 2006), and the figures for Bangladesh are almost similar. In fact, rice production has an important relation with households and national food security, poverty alleviation, and political stability in agro-based

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countries. Its cultivation, in Bangladesh, is characterized by mostly subsistence farming (86%), HYV-dominated, agrochemical-intensive, rice-based monoculture, irrigated, and has followed a traditional cultivation process. Rice production has many positive environmental externalities, like climate control, flood reduction, reduced soil erosion, groundwater recharge, and water purification. Simultaneously, its negative environmental externalities are well documented. Admittedly, the excessive use of chemical fertilizers and pesticides are major sources of water, soil, and air pollution (IRRI, 2004). Moreover, "slash and burn" agricultural technique in upland areas accelerates surface run-off and erosion of topsoil and terrestrial root zone diversity. These practices have also negatively impacted the rice field's associated environmental services. It is recognized that methane released from wetland rice field is a big source of greenhouse gas causing global warming (Khalil *et al.*, 1998).

Input-based rice farming raises many environmental concerns in Bangladesh. Jahiruddin and Satter (2010) documented soil-related problems such as soil salinity, compactness, degradation, acidity, water logging, and drainage impedance due to intensive cultivation. An impressive amount of literatures (e.g. ADB, 2004; Roy *et al.*, 2013a; Roy *et al.*, 2013b) have found that the present rice production trends are not ecologically sustainable and profitable in the long run, for which they identified many reasons like depletion of soil organic matter, extinction of biodiversity, water pollution, rice price fall, and food price speculation. Additionally, poverty of subsistence growers is a significant setback of accessing quality seed, irrigation, technology, and other agricultural input that hamper achievement of the expected yield. Literature suggests three emerging challenges of achieving Sustainable Agriculture (SA): (i) land declination annually by 1% due to urbanization, river bank erosion, and so on (MoA, 2013), (ii) defragmentation of agricultural land due to population pressure (Rahman and Rahman, 2008), and (iii) arsenic hazards caused by the extensive underground water extraction (Meharg and Rahman, 2003). Furthermore, Bangladesh is a highly climate vulnerable country, and agricultural sector is under grave threat because of sea-level rise and increasing salinity in the whole Southern part (ActionAid, 2011). For these challenges, promoting food, fiber, and environmental security pose a great challenge for Bangladesh.

Considering these problems, government has taken many long and short-term initiatives in agricultural extension and development. Specifically, the Department of Agricultural Extension (DAE) has been conducting many projects and programs in order to enhance farmer's capacity, reduce yield gaps, conserve and improve natural resources. In addition, government introduced fertilizers and irrigation subsidy as well as prepared several policies such as national seed policy, and IPM policy. However, studies reported that input subsidies were not benefiting small and marginal farmers. Similarly, Mandal (2006) illustrated that policy documents were not empirical, and based on notional ideas. It is observed that huge population pressure and extreme resource constrain are prime impediments of achieving SA.

Research on driver of sustainable rice farming is scarce. Notably, based on historical data, Baffes and Gautam (2001) examined the sustainability of rice production growth in Bangladesh. In India, developing an index, Gowda and Jayaramaiah (1998) compared sustainability of different rice production systems. Moreover, country's key development publications, namely, National Agricultural Policy (2010), Poverty Reduction Strategy Paper (IMF, 2012), and National Sustainable Development Strategy (MoEF, 2008) stress the issue of SA. However, a succinct roadmap identifying essential drivers is not properly addressed. The study fulfills this research gap.

Understanding that quantification is imperative enables policy makers and researchers to gain an appreciation of the extent of a problem, which may not be understood by anecdotal evidence. This study examined determinants influencing sustainable irrigated and rainfed rice farming using primary data collected through 390 rice growers' survey in areas that represent the major three rice growing ecosystems, namely, irrigated, rainfed lowland, and upland. We aimed to provide clear-cut recipes for policy implications, which would be useful for sustainable rice production systems.

Drivers of Sustainable Irrigated and Rainfed Rice Farming: A Theoretical Foundation

Sustainable farming refers to "the enhancement of environmental quality and the resource base of agriculture, provide human food and fiber needs, is economically viable, and improves the quality of life for farming community over the long term" (ASA, 1989). Considering more operationalizing aspects, Gowda and Jayaramaiah (1998) opined that farming sustainability is a process to manage soil and water resources to raise productivity and to fulfill the needs of farming community without compromising agroecosystems. According to the late Robert Rodale "sustainability is a question rather than answer" and the question can best describe if the farming process becomes productive, competitive, and efficient; simultaneously, protecting and enhancing the natural environment and condition of farmers and society as a whole (Unilever, 2002). More precisely, Pretty (2008) explored key drivers of sustainable farm as four principles: integrated management, minimizing the use of agrochemicals, development of human, and social capital.

Sustainability is a complex phenomenon, and heterogeneous drivers only can give an operational picture of it. For example, Stockle *et al.* (1994) used nine factors for examining the relative sustainability of a farming system, e.g. productivity, profitability, social acceptance and so on. Likewise, researchers determined the most important drivers to defining sustainable farming such as farmer's knowledge and decision making (Garforth, 1993), increasing the competence of farmers (Van den Ban, 1993), nutrient management and diversified income sources (Kater *et al.*, 2000), maintenance of soil health (Nambiar *et al.*, 2001), increased yields of modern rice varieties (Baffes and Gautam, 2001), land productivity (Chowdhury, 2009), profitability of farming (Gafsi and Favreau, 2010), and food availability (Asadi *et al.*, 2013). Contextualizing the socio-economic and bio-physical condition of Bangladesh, researchers documented several dynamics for navigating sustainable rice farming. However, synthesis from key government documents (e.g. 2012 National Rio+20 Report), it can be said that overall social issues are recognized as vital to addressing sustainable farming development.

The contribution of Modern rice Varieties (MVs) is always an important issue, since adopting MVs in Bangladesh has made a notable progress, obtaining a respectable growth in rice production. The productivity increases led to lower output prices, reduced the cost of production, more farming returns, and enhanced access to innovation. Hossain *et al.* (2007) reported that although the technological progress accentuated the inequality in the rural areas, it significantly increased efficiency in input use, employment of hired labor, and grower's income. In that situation, an effective and efficient extension service is important, specifically for the adoption of sustainable farming practices and technologies. Moreover, diversified and non-farm income source was a significant factor contributing to rice farming resilience against the stock created by natural disasters (Magor, 1996). Furthermore, World Bank (2006) recognized that decreased soil fertility and higher water pollution are some issues of great concern for irrigated and rainfed rice farming with a prescription of adopting integrated nutrient management and soil quality monitoring.

MATERIALS AND METHODS

Study Area

This study was conducted in three sub-districts of Northwestern part of Bangladesh, which is considered as rice producing hub of the country, namely, Pirganj, Natore Sadar, and Dinajpur Sadar (Figure 1). These sub-districts represent the major three rice growing ecosystems such as irrigated, rainfed lowland and upland accordingly. The basic features of the study area, inter alia, main area of land, crops, farmer's type, rice varieties, and yield are given in Table 1. Mostly loamy soil and rice-based economic activities are common

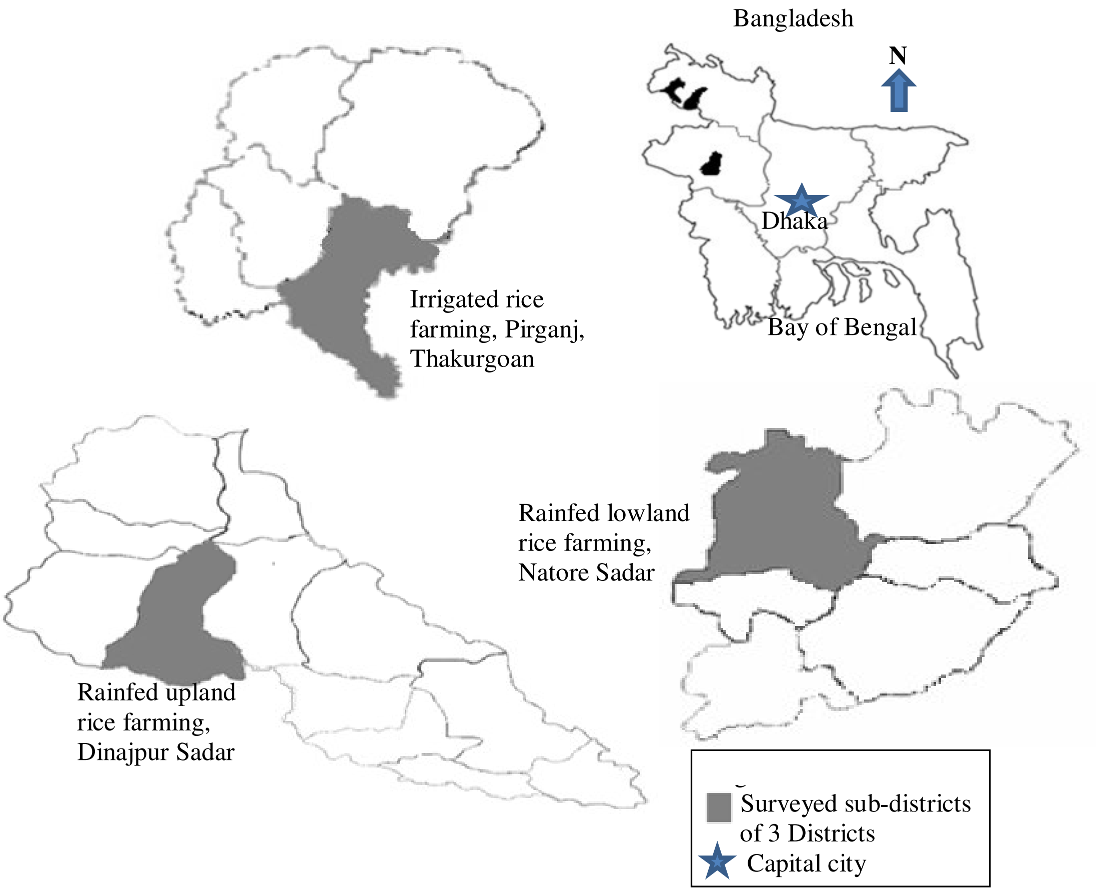

Figure 1. Location of the study area in Bangladesh.

Table 1. Characteristics of the three sub-districts.[a]

Study area	Pirganj, Thakurgoan	Dinajpur Sadar	Natore Sadar
Area (ha)	35341	35488	40129
Main area of land (ha)	Cultivated-29161 Marshy land1638 Forest land-426	Cultivated-29095 Marshy land-715 Forest land-271.20	Cultivated-30000 Marshy land-1024 Forest land-356
Farmers type (%)	Small-75 Medium-21 Large-4	Small-89 Medium-9 Large-2	Small-86 Medium-11 Large-3
Major crop	Rice (Boro, Aman) wheat, oil seed	Rice (Aman, Boro, Aus,) wheat, maize	Rice (Aman, Boro) wheat, jute
Cropping intensity (%)	225	270	218
Major rice variety	BRRI[b] Dhan 28, 29	BR[c] 20, BR21	BR3, BR11
Rice yield (Mt ha^{-1})	Boro-4.2-4.6 Aman-2.0-2.5 Aus[d] -No data	Boro-4.0-4.2 Aman[e] -2.0-2.4 Aus-2.0-2.2	Boro[f] -4.0-4.2 Aman-2.0-2.6 Aus-1.0-1.5

[a] Source: Concerned Agricultural Office, January 2013; [b] Bangladesh Rice Research Institute; [c] Bangladesh Rice, Dhan means rice; [d] Direct seeded or transplanted rice in pre monsoon season; [e] Transplanted rice in monsoon season, [f] Irrigated rice in dry season.

characteristics of these sub-districts. Moreover, in terms of the socioeconomic and biophysical conditions, these areas present a general situation of respective rice-growing ecosystems in Bangladesh.

Household Survey

Data for this study were gathered through the farm households' survey conducted in 15 villages. Since population was rather large, a multistage random sampling technique was employed to select districts, sub-districts, and villages. Given the time, resource, and communication constraints five villages were selected deliberately from each sub-district. Based on the proportional size of farm like the large, medium, and small, 25 households were selected from each village, adopting a simple random sampling method. Applying the "Sloven's formula" (Altares *et al.*, 2003), altogether, 378 households were interviewed using structured questionnaire. The survey instrument was assessed for content and faces validity by a panel of eighteen experts consisting of agronomy, economics, environmental science, and allied vocations. In the selection process, actual rice growers, including the share croppers and contract farmers were considered, excluding non-farm households and landless farmers. The purpose of this process was to get respondents who were actively involved in rice farming, irrespective of whether they owned land or rented it. It was observed that the distribution of farmers based on farm size was representative of the national distribution.

Sloven's formula: Sample size, $n = N/(1+Ne^2)$ (1)

Where, population 'N' and error 'e' were 7,000 and 0.05 (95% confidence level), respectively.

Detailed information on socio-economic condition, income source, extension services, social organization involvement, technology application, nutrient management, and yield were collected through a structured questionnaire. Supplementary information was gathered by observation, key informant interviews, and informal discussion. Selected leader farmers, school teacher, and experienced growers were the key informants interviewed. Household survey was conducted during March to June, 2012. Secondary information was collected from concerned agricultural extension office.

Measurement of Dependent Variable

Empirical examination of determinants of irrigated and rainfed rice farming sustainability was analyzed using stepwise multivariate regression analysis, for which the extent of sustainable rice farming is the dependent variable. Measurement of sustainability is always contested, and it is a relative and approximate quantification. We used proxy indicator to quantify this aspect. For that purpose, we reviewed several publications (e.g. Pretty, 2008; National Research Council, 2010) in order to find statements/indicators that describe rice farming sustainability properly. Accordingly, 15 items were selected under three categories. Statement of the economic pillar defines profitability, contribution of local economy, creation of employment and so on. Food security, standard living, extent of health hazard explains social dimension, and water pollution, erosion of soil and biodiversity, extent of pest and disease occurrence, etc. describes the environmental aspects of rice farming. An attitudinal scale was used to evaluate the sustainability of rice farming. Hence, a five-points Likert scale was developed exclusively for this study. Besides, content and faces validity was evaluated by a panel of experts and a post-hoc reliability analysis was conducted to estimate the reliability of the dependent variable. It was observed that the Cronbach's alpha coefficient of reliability was 0.86, which indicated that the internal consistency was good (George and Mallery, 2003). Data was obtained from respondents on the five-point continuum, namely, strongly agree, agree, undecided, disagree, and strongly disagree with the corresponding weighting factor of 5, 4, 3, 2, and 1.

Selection and Measurement of Explanatory Variables

Review of literature was the main source of explanatory variables. Sustainability is a situational concept, so it is imperative to consider grower's socio-economic and farming bio-physical condition in variable selection. Rice farmers in Bangladesh are overwhelmingly poor and smallholders. Moreover, they have little access to extension services, agricultural inputs, resources, and markets. Their prime concern for rice production is how to increase yield, farm returns, and food security. Thus, in view of social, economic, and environmental conditions of the study area, 12 variables were selected (Table 2) to identify and examine the determinant of sustainable irrigated and rainfed rice farming. Initially, a Pearson correlation analysis was done to observe the relationship among the variables. A high correlation (r> 0.80) was observed between "effectiveness of extension services" and "availability of extension services" variables. Based on the magnitude of interrelationship, "effectiveness of extension services" variable was dropped from further analysis. Similarly, two variables, i.e. "crop diversification" and "equity" were dropped because of low correlation with the dependent variable. A rice-based cropping pattern was dominant in the study areas, and little variation was observed in "diversification of crop" variable. Growers were concerned about the equity issue. However, they expressed financial inability in providing goods and services to the society to a great extent. Perhaps, for these reasons, these two variables did not show strong association with the response variable. Following careful consideration of all variables, finally, nine independent variables with a low degree of correlation with each other and high degree of association with the dependent variable (Table 3) were included in the regression analysis.

Among these variables, "education", "non-farm income source", "availability of extension services", "social capital", "use of resource conserving technologies", and "integrated nutrient management" were strongly correlated with the response variable "sustainable irrigated rice farming".

Table 2. Selected indicators in the initial stage and their measurement. [a]

Variable	Measurement
Level of education	No. of years of schooling of growers
Farm size	Total quantity of farming land, including gardening and fishery
Non-farm income source	No. of family income sources other than agriculture
Availability of extension services	No. of extension contact made by farmers and extension agents
Effectiveness of extension service	Extent of effectiveness of selected extension services
Social capital	Extent of involvement, no. of contact, and confidence to organizations
Equity	Extent of growers opinion on equitable thinking, e.g. labour wages, gender participation, equal right, etc.
Use of resource conserving technologies	No. of technologies used assuming ecologically sound
Integrated nutrient management	Extent of different types of nutrient use and quantity
Crop diversification	No. of crops grown and proportion of acreage of crop to total cropped area
Net farm return	Gross farm income minus production expenses
Land productivity	Physical yield of per unit area

[a] All information were based on activities of the year of 2013.

Table 3. Variables significantly correlated with rice farming sustainability.

Factor	Correlation coefficient		
	Irrigated	Rainfed lowland	Rainfed upland
Level of education	**0.67****	**0.55****	**0.51****
Farm size	-0.23*	-0.22*	0.20*
Non-farm income source	**0.58****	**0.51****	0.47**
Availability of extension services	**0.52****	0.42**	0.41**
Social capital	0.48**	**0.53****	0.41**
Resource conserving technologies	**0.64****	0.46**	0.21*
Integrated nutrient management	**0.57****	0.43**	-0.22*
Net farm return	0.34**	0.31**	0.41**
Land productivity	0.24*	**0.57****	**0.63****

** Significant at 0.01 confidence level, * Significant at 0.05 confidence level.

The variable "use of resource conserving technologies" hereafter is referred to as "use of technologies". These strongly correlated variables were added in the regression analysis in order to capture their role in facilitating irrigated rice farming sustainability. Farmer's level of education is the key social factor for sustainable agricultural development. Moreover, extension service, social network plays a significant role in better production by conveying necessary information of market and quality seed, appropriate technologies and innovations, and knowledge and skill to agricultural risk management. Since the studied farmers were largely smallholder, diversified income source would increase the possibility of access to HYVs, irrigation, innovative farming practices, and essential nutrients. Nutrient management is important for retaining soil health, and farming sustainability mostly depends on the maintenance or improvement of soil health.

Regarding the sustainability of rainfed lowland rice farming, "education", "non-farm income source", "social capital", and "land productivity" variables were added in the regression analysis (Table 3), since these variables were found to be significantly correlated with the explained variable. Moreover, only "education" and "land productivity" variable added in the regression analysis related to the sustainability of rainfed upland rice farming, as these two variables were found to be strongly associated with the explained variable (Table 3). In both cases of sustainable rainfed lowland and upland farming, land productivity is a vital issue, as production of rainfed rice is much lower than irrigated rice. Farmers stressed that without improving yield of rainfed rice, economic viability of this farming region was a distant dream.

Model Specification

Three regression models were developed to examine the determinants influencing irrigated and rainfed rice farming sustainability.

Model 1: Sustainable Irrigated Rice Farming

As discussed in the theoretical foundation, irrigated rice farming sustainability is influenced by several social, economic, and environmental factors. Accordingly, it was hypothesized that sustainable irrigated farming in the study area was influenced by a number of predictor variables: $X1, X2, X3$ …… Xn (Table 2). The model was specified as follows:

$$Y = a + b_1X_1 + b_2X_2 + \cdots + bnXn$$

Where, Y is the dependent variable sustainable irrigated rice farming, a is the intercept, and b_1, b_2…… bn are the coefficients of independent variables X_1, X_2 ……Xn.

Model 2: Sustainable Rainfed Lowland Rice Farming

This model was hypothesized as dependent variable was being contributed by a set of explanatory variables: X_1, X_2 ……*Xn* (Table 2).

$Y= a+b_1X_1+b_2X_2+ \cdots +bnXn$

Where, *Y* is the dependent variable sustainable rainfed lowland rice farming, *a* is the intercept, and b_1, b_2…… *b*n are the coefficients of independent variables X_1, X_2 ……*Xn*.

Model 3: Sustainable Rainfed Upland Rice Farming

The dependent variable rainfed upland farming sustainability was hypothesized as being contributed by a number of independent variables: X_1, X_2 ……*Xn* (Table 2). The model was specified as follows:

$Y= a+b_1X_1+b_2X_2+ \cdots +bnXn$

Where, *Y* is the dependent variable rainfed upland farming sustainability, *a* is the intercept, and b_1, b_2…… *b*n are the coefficients of explanatory variables X_1, X_2 ……*Xn*.

RESULTS

Determinants of Irrigated Rice Farming Sustainability

Five explanatory variables, namely, "level of education", "non-farm income source", "availability of extension services", "use of technologies", and "integrated nutrient management" were significantly associated with the magnitude of irrigated rice farming sustainability (Y), and were added step by step in the regression analysis. With the addition of these independent variables, both the multiple *R* and R^2 values increased, and they had significant explanatory power in the models. The final model with five explanatory variables explained 76% of the variation in the extent of sustainable irrigated rice farming (Table 4). The other four variables, namely, "farm size", "social capital", "net farm return" and "land productivity" could not enter the final

Table 4. Coefficient of independent variables included in the irrigated rice farming model.

Variable	Unstandardized coefficients		Standardized coefficients beta	*t*	Significance
	B	Standard error			
Constant	58.61	6.400		9.31	0.001
Level of education	0.521	0.204	0.205	3.116	0.000
Non-farm income source	0.39	0.168	0.181	2.771	0.001
Availability of extension services	0.401	0.149	0.142	4.39	0.000
Resource conserving technologies	0.553	0.217	0.221	3.675	0.000
Integrated nutrient management	0.668	0.199	0.201	3.359	0.001

Summary of the irrigated rice farming sustainability model

Model	*R*	*R* square	Adjusted *R* square	Standard error
1	0.773[a]	0.597	0.592	6.193
2	0.799[b]	0.638	0.634	5.340
3	0.827[c]	0.683	0.679	6.871
4	0.851[d]	0.724	0.719	4.936
5	0.872[e]	0.760	0.754	5.857

[a] Predicators: Constant, level of education; [b] Predicators: Constant, level of education, non-farm income source; [c] Predicators: Constant, level of education, non-farm income source, availability of extension services; [d] Predicators: Constant, level of education, non-farm income source, availability of extension services, resource conserving technologies, [e] Predicators: Constant, level of education, non-farm income source, availability of extension services, resource conserving technologies, integrated nutrient management.

regression model, due to their weak association with the dependent variable (Y). The *F* ratio of independent variables added in the final model was found statistically significant at 0.001 confidence level. The results indicated that the explanatory variables included in the model were appropriate.

Besides these, all independent variables had a positive contribution to the dependent variable (Table 4). Among them “use of technologies” influenced the most (0.22 unit) followed by the variable “grower’s education”. An increment in one unit of use of technologies leads to an increment in sustainable irrigated rice production by 0.22 unit. This is rational as the significance of resource conservation technologies is beyond increasing productivity by enabling us to safeguard nature. They play an increasingly central role in preserving land and biodiversity, and maximize water resources. Likewise, grower’s level of education and nutrient management influenced by about the same magnitude in achieving sustainable irrigated rice farming. Education is an essential ingredient for development, and knowledge and skills have an inextricable link with the sustainability. The literature on the influence of education as well as mixed nutrient management in sustainable farming is rich. The least contributed explanatory variable was availability of extension services. The result shows that a unit of increment in extension service leads to change in grower’s knowledge, adoption of innovation, appropriate variety selection and, consequently, better production by 0.14 units (Table 4). This clearly indicates that the provision of agricultural advisory services is significant but not an adequate condition for promoting irrigated farming sustainability. The other explanatory variables like social capital, net farm return, and so on, influence the dependent variable to a certain extent. However, owing to their weak association with the degree of irrigated farming sustainability, they were not considered in the regression model.

Determinants of Sustainable Rainfed Rice Farming

Four explanatory variable, namely, “level of education”, “non-farm income source”, “land productivity”, and “social capital” were moderately correlated with the degree of rainfed lowland rice farming sustainability, and these variables were entered step by step in the regression model. Collectively, these variables explained almost 75% of the variation in the dependent variable (Table 5). The F ratio of the independent variables in the final model was found to be statistically significant at 0.001 confidence level. Moreover, the result indicated that productivity of land was the most influenced explanatory variable among others in fostering rainfed lowland farming sustainability. A unit of increment in land productivity leads to promote economically viable, socially responsible, and ecologically sound rainfed lowland rice farming by 0.32 units. The other three independent variables also contributed individually by approximately 0.20 units in a unit of increment in sustainable rainfed lowland rice farming.

In regard to rainfed upland rice farming sustainability, two explanatory variables, i.e. “level of education” and “land productivity” entered step by step in the regression model for the above mentioned reasons. These variables explained by about 60% of the variation in the sustainability of rainfed upland rice farming (Table 6). The *F* ratio of the independent variables in the final model was found to be statistically significant at 0.001 confidence level, which indicated that the variables added to the model were correct. Additionally, the result showed a tendency towards an increment in sustainable rainfed upland rice farming by almost 0.37 units with one unit of increment in land productivity. Likewise, grower’s level of education fairly influenced the sustainability of rainfed upland farming systems as well.

Table 5. Coefficient of independent variables included in the rainfed low land rice farming model.

Variable	Unstandardized coefficients		Standardized coefficients beta	t	Significance
	B	Standard error			
Constant	47.936	5.205		8.613	0.000
Level of education	0.455	0.176	0.189	3.447	0.000
Non-farm income source	0.504	0.217	0.248	4.301	0.001
Land productivity	0.551	0.223	0.318	3.812	0.000
Social capital	0.764	0.234	0.206	3.265	0.001
Summary of sustainable rainfed low land rice farming model					
Model	*R*	*R* square	Adjusted *R* square	Standard error	
1	0.791[a]	0.625	0.620	7.660	
2	0.824[b]	0.678	0.674	6.043	
3	0.839[c]	0.714	0.710	6.548	
4	0.861[d]	0.749	0.743	5.442	

[a] Predicators: Constant, level of education; [b] Predicators: Constant, level of education, non-farm income source; [c] Predicators: Constant), level of education, non-farm income source, land productivity, [d] Predicators: Constant, level of education, non-farm income source, land productivity, social capital.

Table 6. Coefficient of independent variables included in the rainfed up land rice farming model.

Variable	Unstandardized coefficients		Standardized coefficients beta	*t*	Significance
	B	Standard error			
Constant	43.887	12.134		4.344	0.000
Level of education	0.687	0.199	0.299	4.093	0.001
Land productivity	0.785	0.254	0.368	3.445	0.000
Summary of sustainable rainfed upland land rice farming model					
Model	*R*	*R* square	Adjusted *R* square	Standard error	
1	0.695[a]	0.483	0.480	5.548	
2	0.757[b]	0.573	0.566	4.942	

[a] Predicators: Constant, level of education, [b] Predicators: Constant, level of education, land productivity.

DISCUSSION

Results show that grower's level of education is a common contributing factor for both types of rice farming sustainability (Tables 4, 5, and 6). This is justified as to a certain extent. Since technically knowledgeable, skilled, and competent farmers are better able to plan and manage agrarian farm, risk, and vulnerability. Moreover, they can cope with new farming realities, new challenges, and explore new opportunities to actualize sustainable production. The UNESCO World Conference on Education for Sustainable Development (SD) stresses the influence of education in fostering sustainability of different sectors. Consistently, IFAD (2010) highlights education as one of the four key issues to pursue the agenda for rural economic growth. Moreover, World Bank (2008) recognizes that in an era of resource crisis education is often the most valuable asset for better rural socio-economic development. Considering a broad spectrum of sustainability, Barth and Michelsen (2012) explored three pathways how education contributes to development: (i) individual action and behavior change, (ii) organizational change and social learning, and (iii) inter- and trans-disciplinary collaboration.

Poverty is a primary concern of rural growers, and agriculture is a principal source of their income to escape from poverty. Discussion with farmers revealed that they suffered an extreme shortage of hard cash in the peak season, as they did not have employment in the lean season. As a result, they could not purchase timely irrigation, recommended fertilizers, and quality seed that hamper achievement of the expected yield. In that situation, non-farm income increases their access to agricultural inputs, market, and resources. These have a knock-on effect on economically viable production. Perhaps for that reason, non-farm income significantly contributed sustainable rice production (Tables 4 and 5). Consistent with our result, de Janvry *et al.* (2005) showed that participation in nonfarm activities has a positive spillover effect on household farm production. Moreover, Poverty Reduction Strategic Paper of Bangladesh (IMF, 2012) underlines the diversified income sources of farmers for promoting sustainable farming and livelihoods. Hossain (2004) also underscores that it is a challenge to decision makers to devise and implement programs and policies that facilitate diversified income sources in favor of farm households.

The results revealed that environmental factors were the dominant determinants for irrigated condition while land productivity was the influential factor for rainfed rice farming sustainability (Tables 4, 5, and 6). Justification for this phenomenon is quite valid. It was observed that irrigated rice growers cultivated HYVs more than rainfed growers. Usually, HYVs are responsive to fertilizers, pesticides, and irrigation, and produce higher yields. Consequently, negative environmental impacts come from rice farming besides several positive externalities. In addition, yield of rainfed rice is lower than irrigated rice. The average yield of irrigated rice was 3.84 metric ton ha^{-1} in 2009-2010, and the figure for rainfed lowland and upland was 2.45 and 2.28 metric ton ha^{-1} respectively (BBS, 2011). Although irrigated rice production accrues some extra costs for irrigation and fertilization, its higher production surpasses the costs (e.g. Baten and Hossain, 2014).

In the context of food insecurity and climate change, application of resource conserving practices and technologies is imperative for intensification of sustainable production, as well as to minimize negative ecological impacts. Substantial amount of literature have reported that practices like using the leaf color chart, alternative wetting and drying irrigation, and zero tillage as well as technologies such as deep urea placement, IPM, etc. improve productivity (NCB, 2004), cost saving, and efficiency in input utilization (Singh *et al.*, 2011). Besides these, nutrient management is an important practice for saving soil health, on which sustainable production is dependent to a great extent. In principle, integrated nutrient management is the combined use of organic, biological, and mineral fertilizers. Moreover, mixed cropping, cropping rotation, and use of on-farm and off-farm vegetable and animal waste through recycling is a vital part of integrated nutrient management. Research shows (Pretty, 2008; Singh *et al.,* 2011) that combined management of nutrient conserves and improves the biological, physical, and hydrological properties of soil, biodiversity, and other natural resources, which enhances farming system efficiency, resiliency, and productivity, and reduces emissions of CO_2, CH_4 and NO_2. Generally, more negative environmental concerns come from irrigated rice farming (specifically, considering the extent of methane gas emissions) than rainfed lowland and upland rice, and these two factors rationally influence the ecological sustainability aspect of rice production (Table 4).

Public funded extension service is a major source of agricultural information in many countries. However, it is found that existing agricultural advisory services are inadequate and inefficient in Bangladesh, though farmers depend on it. In fact, they have no alternatives. By overcoming several financial, technical, and administrative limitations, this service is a significant medium for knowledge dissemination, and technology transfer to improve farm household's livelihoods and well-being (Roy *et al.*, 2013c). To shift rice farming from highly external input-dependent, conventional, and monoculture-based system towards mosaics of sustainable production systems, a demand-oriented, decentralized, and participatory agricultural extension service is indispensable. This conclusion is supported by the result of the regression analysis that revealed that availability of extension services is a contributing determinant for irrigated rice farming sustainability (Table 4).

Generally, the largest harvest type rainfed lowland rice is non-irrigated and, compared to irrigated rice, it is less dependent on external agricultural inputs. Farm household survey revealed that rainfed lowland rice produced average yield, applying a minimum amount of irrigation, and agro-chemicals. Moreover, better farm management such as water harvesting; physical and mechanical pest, disease, and weed management, etc. are the vital practices for environmentally sound, and socially and economically sustainable rainfed lowland rice farming. In this link, organizational involvement, local networks, mutual actions, and partnerships can assist growers in promoting sustainable rice farming. Hence, a significant contribution to social capital in the sustainability of rainfed lowland rice farming can be justified (Table 5).

CONCLUSIONS

Growers are overwhelmingly dependent on irrigated rice for its yield potentiality, and this rice cultivation produces many negative environmental externalities such as arsenic hazards in the whole South Western part of Bangladesh. On the other hand, rainfed rice causes negative environmental problems to a lesser extent, and yields lower production than irrigated rice. However, in the context of a burgeoning population growth, there is no alternative to boost rice production to feed the extended population. It is in this context that identifying and examining the determinants of sustainable irrigated and rainfed rice farming merits a closer look.

Results indicate that farmer's level of education is a common influential determinant for all types of rice farming sustainability. Moreover, the results indicate that the application of resource conservation technology and land productivity are the most dominant determinants of irrigated and rainfed rice farming sustainability, respectively. The study highlights that: (i) farmers' human capacity development is a major factor for sustainable rice farming, (ii) the application of effective resources conservation and enhancing practices and technologies are vital for increasing productivity, as well as reducing negative environmental impacts, and (iii) raising land productivity is a decisive determinant for the sustainability of rainfed rice farming. This study is based on the three rice growing ecosystems, and did not consider deep water, tidal and not tidal saline water rice. This is a limitation of our research in terms of comprehensive policy implications. An empirical evaluation of drivers of agri-environmental sustainability is a future research area. Based on evidence, the policy implications should emphasize the followings:

Developing farmer's knowledge, skill, and competency in water and nutrient management by adopting "farmer-to-farmer" knowledge transfer, and "social learning" approach. Agricultural advisory services and local producer organizations can play a leading role in this regard.

Exploring and disseminating ecologically sound agricultural practices and technologies to intensify sustainable rice production. In this case, the use of local knowledge, gender participation, and adopting a participatory method is imperative.

Developing stress-tolerant and high yielding rainfed rice varieties in order to increase land productivity, production stability, and farmer's income.

Generating opportunities for diversified non-farm income by investing in marketing facilities, value-added agriculture, women producers, and rural youths.

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عوامل تعیین کننده پایداری برنجکاری آبی و دیم در بنگلادش

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چکیده

امنیت غذایی و فقرزدایی در آسیا به پایداری تولید برنج وابسته است. در این پژوهش، عوامل تعیین کننده پایداری برنجکاری آبی و دیم در بنگلادش بررسی شدند. داده های مطالعه از طریق آمار برداری از خانوارهای کشاورزان که شامل ۳۹۰ برنجکار بود(تعداد نمونه ها با استفاده از فرمول اسلون Sloven تعیین شد) و نیز با انجام مشاهدات ، مصاحبه با افراد خبره، و بحث های عمیق با ذی‌مدخلان مربوط جمع آوری شد. اعتبار سنجی و درستی ابزار این پژوهش را خبرگان و کارشناسان با بررسی محتوی آن ها ارزیابی کردند و افزون بر آن اعتبار سنجی با روش تجزیه پساآزمون(post-hoc) و ضریب کرنباخ که ۰/۸۶ بود نیز انجام شد. بر پایه تجزیه رگرسیونی گام به گام ،در این پژوهش معلوم شد که (۱) دانش ، مهارت و کارآمدی برنجکاران عوامل عمومی موثردر تولید پایدار برنج هستند ،(۲)کاربرد فناوری حفاظت از منابع در برنجکاری آبیاری شده نقش موثری در افزایش بهره وری و حفظ منابع طبیعی دارد،(۳) بالابردن بهره وری زمین عاملی تعیین کننده در پایداری برنجکاری است. در این مقاله بر پایه شواهد این پژوهش کلیات نتایج برای سیاستگزاری ارایه شده است.