Paddy Farmers' Adaptive Measures to Salinization in Southwest Coastal Region of Bangladesh

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Abstract

Paddy in the southwest coastal region of Bangladesh continues to support food security and GDP growth. But in the recent past, it has decreased due to salinity. This study aims to detect the most resilient paddy variety to the salinity intrusion condition and identify the most important fertilizer that contributes to more paddy cultivation in this situation. Translog production function is used to assess the impact of salinity on Aus, Aman, and Boro paddy in the salinity affected southwest coastal region and salinity free northwest coastal region for comparison. This estimate is based on collected data from the sample farmers of southwest and northwest Bangladesh through the purposive sampling and questionnaire survey. dSm^{-1} of paddy farms of sample farmers are measured by the salinometer. The findings suggest that proper utilization of essential inputs can play an important role to produce paddy properly under the salinity prevailing condition.

Keywords: Ecological economics, Paddy production, Adaptation, Disaster risk reduction, Salinity

1. Introduction

Southwest coastal region is the most susceptible area to salinity due to natural and man-made hazards from sea-level rise, cyclone and storm surge, drought, shrimp farming, Farakka Barrage, and unplanned coastal embankment project (CEP) (Iqbal and Sarker, 2018). For instance, cyclone, and surge wave bring salinity from the sea and degrade crop farms and inland waterbody (Baten et al., 2015; Khan et al., 2015). Drought causes the earth to parch and a considerable hydrologic imbalance resulting in acute salinity problems (Meng et al., 2017). The rise in sea-level is responsible for creating the salinity in the estuaries because the saltwater boundary moves landward (Fagherazzi et al., 2020). Brackish water from shrimp cultivation has aggravated the salinity of soil and groundwater aquifers (Iqbal and Milon, 2018). Farakka Barrage controls water navigation in the southwest coastal region of Bangladesh. Very low discharge of water by this Barrage in the dry months (May-November) causes salinity problems. Improper site selection and structural fault of polder destruct the natural flow of water and develop salinity (Iqbal and Sarker, 2018).

Salinity is a composition of soluble salts of carbonate, bicarbonates, chlorides, and sulfates of sodium, calcium, magnesium, and potassium in concentrations and makes disturbance to the growth and yield of growth (Provin and Pitt, 2017). The soil reactions, electrical

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conductivity (EC), and exchangeable sodium percentage (ESP) are some of the indicators that reflect the degree of soil and water salinity. Generally, soil with a pH < 8.5, ESP < 15 and EC > 4 dSm^{-1} are categorized as saline soils and for alkali soils the parameters are pH > 8.5, ESP > 15 and EC < 4 dSm^{-1} (Shahid et al., 2018). The presence of soluble salts in the soil affects the transmission and availability of nutrients to plants (Otlewska et al., 2020; Iqbal, 2020). The excess salts become toxic to plants and in the long term damage the soil reversibility. The salinization of land contaminates groundwater aquifers through the seepage of salts and affects the quality of water used for irrigation and badly hampers crop productivity in the coastal region (Krishan et al., 2020).

The effects of salinity and paddy production are well established (Porcel et al., 2016). Salinity restricts plant growth of paddy by ion toxicity and osmotic stress (Parvin et al., 2020). Ion accumulation (N_a^+ and Cl^-) in the soil solution creates osmotic stress that reduces the water availability to the roots and develops paddy plants to wilt as roots which cannot absorb sufficient water to replace that loss from transpiration (Safdar et al., 2019; Schulze et al., 2019). Ion toxicity creates a disturbance in leaves and further develops nutrition deficiencies of paddy (Chen et al., 2019). High salt concentration may stop root growth as well as shoot growth of paddy plants (Kibria et al., 2017). Paddy suffers from salt injury at concentrations equivalent to the electrical conductivity of the soil saturation extract of ECe of 4 dSm^{-1} or higher (Bimpong et al., 2016). The extent of salt injury in paddy depends on the category and degree of salinity, duration of exposure to salt stress, cultivars, the growth stage of paddy, water quality, age of seedling, method of planting, soil properties, temperature, and solar radiation (Gamalero et al., 2020).

Resource allocation and transformation are directly affected by salinity (Li et al., 2019). Paddy farmers of the southwest coastal region cultivate fewer amounts of land and apply an inadequate amount of essential inputs for paddy cultivation. The high intensity of salinity restricts paddy cultivation and motivates paddy farmers to keep their land fallow during the pre-monsoon (March to early-June) and post-monsoon (October to February). As a consequence, food security and paddy farmers' income, and livelihood will be at risk which needs effective adaptation practice.

In response to the facts presented above, adaptation strategies are needed to be discussed and implemented urgently. Effective and sound adaptive practices are highly required to maintain sustainable paddy production under the salinity condition. Paddy farmers' adaptive practice to salinity is the process in which they enable them to respond and adjust to the actual or potential impact of salinity and produce paddy under the salinity condition (Radanielson et al., 2018). For the paddy cultivation process, there are many potential adaptive measures to alter management to deal with salinity and paddy production. These adaptation practices include salinity tolerance of paddy (Kim et al., 2017), proper tillage in paddy farm (Aryal et al., 2019), water management (Yohannes et al., 2017), selection of appropriate fertilizers and their optimum dose (Akhtar et al., 2020), salinity test in the paddy farms for cropping (Meyer et al., 2016), weather forecast (Singh et al., 2018), wider use of technology to conserve soil moisture (Lievens et al., 2017), wider use of integrated pest pathogen management (Lamichhane et al., 2016), and other essential inputs such as labor utilization (Chen and Gong, 2020). According to an extensive body of empirical works, all these factors are essential for developing paddy productivity conditions under the prevailing salinity in the paddy farm. Paddy farmers in the southwest coastal region argue that appropriate fertilizers and their optimum dose, salinity test in the paddy farms for cropping, and the number of optimum labor for paddy production are the most essential adaptive measures for better paddy production under the salinity condition. Thus, the following questions remain to address effective adaptive measure: Which variety of paddy is mostly affected by salinity? Which fertilizer gains the principal role for effective adaptive measure to cultivate paddy in salinity intrusion condition? What is the optimum number of labor for paddy cultivation? To answer these research questions, this study sets its research objectives as to detect the most resilient paddy variety in the salinity intrusion condition, to identify the most important fertilizer for effective adaptive measure to cultivate paddy in salinity intrusion condition, and to determine the optimum level of labor for paddy cultivation.

The study provides an overview of adaptation in paddy to salinity. In general, it registers an improvement over the present literature in the following viewpoints: (1) the study applies cross-sectional data for both salinity affected and salinity free regions to make a proper comparison which is completely absence in the existing literature; (2) it measures simulation to get the appropriate amount of required inputs for salinity affected paddy cultivation; (3) it calculates marginal return so that paddy farmers can make a decision easily about paddy production in the salinity affected region; (4) it highlights the structural stability of different paddy models to look at the steadiness of the impacts of salinity on paddy cultivation; and (5) providing the numerical values of salinity for proper empirical investigation in paddy cultivation in terms of ecological economics.

Following the first section, the literature review is discussed in Section 2. Section 3 highlights the theoretical farmwork. Section 4 focuses on the research methodology. Section 5 depicts the estimation results for the regression models, simulation, and marginal return. Finally, Section 6 puts on end to the study with conclusion and policy implications.

2. Literature Review

Land, soil, hydrology, and agro-climatic parameters are the basic components of the coastal ecosystem (Iqbal, 2015). Paddy cultivation largely depends on the quality of these natural resources. Paddy can be grown under salinity conditions, but its contribution to cropping intensity is very low. A high level of salinity during the sowing and growth stages of paddy is very harmful. Abdullah et al. (2019) report that there is a strong association between salt dynamics and coastal paddy fields of Bangladesh. In salinity affected soil, paddy growth is badly hampered by salt accumulation in the root zone of paddy. Paddy plants are suffering from a salt injury at the concentration equivalent of ECe of 4 dSm^{-1} or higher (Rajaie and Tavakoly, 2016). Paddy plants cannot tolerate excessive salinity at the level ECe>7 and acidity PH<4 (Moussa et al., 2020). Salinity is not a static entity. It varies from time to time and from location to location. For instance, the productivity of paddy may vary with different degrees of salinity. When there are 3.0 of ECe and 2.0 ECw in the crop farm, the farmer can get 100% productivity when other things remaining the same and it will be 50% when there are 7.2 of ECe and 4.8 ECe in the crop farm (Ayres and Westcot, 1994).

Salinity in the shrimp farming region can be 500% higher than in the non-shrimp farming region and continuous and unregulated shrimp farming has immense impacts on paddy production (Iqbal and Milon, 2018). Shrimp ponds have a great contribution to degrade paddy farms by brackish water in the southwest coastal region of Bangladesh. Prolonged shrimp farming adjacent to paddy farms has significantly degraded the soil quality, drastically reduced paddy production, and hampered the rice ecosystem (Jinguji et al., 2018). Rahman et al. (2011) report that shrimp farming (Gher), rising sea-level, cyclone, and decreasing river flow are the main factors responsible for enhancing salinity in the southwest coastal region of Bangladesh. Different findings also get in the study conducted by Bennett et al. (2009). They point out that water management in the Netherlands is a dynamic process with shallow water tables and a strong interaction between groundwater and surface water, causes high levels of salinity.

Some studies also appreciated agronomic management, crop intensification, and water resource exploitation. For example, Habiba et al. (2012) stress that improper intensification of paddy and unwise use of water resources may hamper the adaptation measures in paddy. Paddy selection as salinity adaptation is a useful technique for a better agrarian society and better livelihood options (Moniruzzaman, 2015). High yielding seed, optimum use of necessary and basic fertilizer, proper utilization of labor force, water management, and pest control can improve the productivity of paddy under the salinity intrusion condition (Morton, 2020). Developing paddy tolerant cultivars able to tolerate soil stress and salinity (Kumar and Khare, 2016). Iqbal and Sarker (2018) suggest that Aman paddy is the best tolerant variety to salinity because it is a rain-fed variety and rainwater can diminish the level of salinity.

In recent years, several modeling studies have been done on the likely effects of climate change on paddy production. However, there have been no similar study in the field of salinity and its impacts on paddy cultivation. Most of the existing literature in this field follow a qualitative approach. For better empirical assessment, it is essential to apply a quantitative approach in the field of salinity and paddy cultivation. This study tries to fulfill such kind of gap.

3. Analytical Approach

3.1 Translog production function

Translog production function was first proposed by J. Kamenta in 1967 for the approximation of the constant elasticity of substitution (CES) production function along with a higher-order Taylor series (Pavelescu, 2011). Interaction terms can be estimated in a symmetric system of derived factor share equations that improve estimation properties relative to a single equation (Thompson, 2006). Under this consideration, we can write the production function as the following form:

$$InY = lnA_3 + \alpha_3 lnK + \beta_3 lnL + \chi_3 ln^2(K/L) \tag{1}$$

Later in 1971, Grilichs and Ringstad proposed two categories of production function following the structure of Kamenta's production function (Pavelescu, 2011). The first category was obtained by imposing the perfect homogeneity condition that has $a+b=1$. In this situation, the production function became a labor productivity function:

$$In(Y/L) = lnA_2 + \alpha_2 ln(K/L) + \chi_2 ln^2(K/L) \tag{2}$$

Equation (2) possesses the second-order polynomial in the logarithms of the single input with the capital-labor ratio.

The second category was defined in conditions of relaxing the constraints imposed on the parameters in the Kamenta's function to test the homotheticity conditions and can be written as follows:

$$InY = \alpha + \beta_L lnL + \beta_K LnK + \beta_{L^2} lnL^2 + \beta_{K^2} LnK^2 + \beta_{L\,K} lnLlnK \tag{3}$$

Christensen, Jorgenson, and Lau wrote the details structure of translog production function or transcendental logarithmic production function in their two papers published in 1971 and 1973. It introduces interaction terms and can be estimated in a symmetric system of derived factor share equations that improves estimation properties relative to a single equation (Thompson, 2006; Iqbal, 2015). The generalized form of translog production function can be written as follows:

$$InY = lnA_{\alpha_i,\beta_{ij}} + \sum_{i=1}^{n} \alpha_i lnX_i + (\frac{1}{2}) \sum_{i=1}^{n} \sum_{j=1}^{n} \beta_{ij} lnX_i lnX_j \tag{4}$$

The form of the marginal product of this function is structurally similar to the Cobb-Douglas production function and can be written as follows:

$$\frac{\delta Y}{\delta X} = \alpha_i + \sum_{j=1}^{n} \beta_{ij} lnX_i \tag{5}$$

The marginal rate of transformation between two factors of production is also possible to derive from the marginal product of translog production function and can be written as:

$$\frac{\delta X_i}{\delta X_j} = \frac{\alpha_i + \sum_{i=j}^{n} \beta_{ij} lnX_i}{\alpha_j + \sum_{i=j}^{n} \beta_{ij} lnX_j} \tag{6}$$

The translog production function has numerous advantages such as it is commonly used in the elasticity of substitution (Blackorby and Russel, 1989), it is a flexible functional form providing a second-order approximation and support the concavity condition of production function (Tsionas and Izzeldin, 2018), it can easily explain cross and marginal effects of inputs (Lin and Raza, 2020). The translog production guided regression model has a greater contribution to the assessment of impacts through the estimation process of parameters.

3.2 Simulation

The quickest way to desirable feasible production plans is to list them when we have any information gap about input price but output and labor wage are occurring, that is, we can list all combinations of input-output by the simulation process. The set of combinations of input-output, e.g. X_i and Q that comprise a technologically feasible way to produce is called a production set (Varian, 2010). In the simulation exercise, it is possible to get the predicted yield obtained by substituting the physical optimum level of input derived from the translog production function. A production set of X_i and Q of a farm is shown in Figure 1.

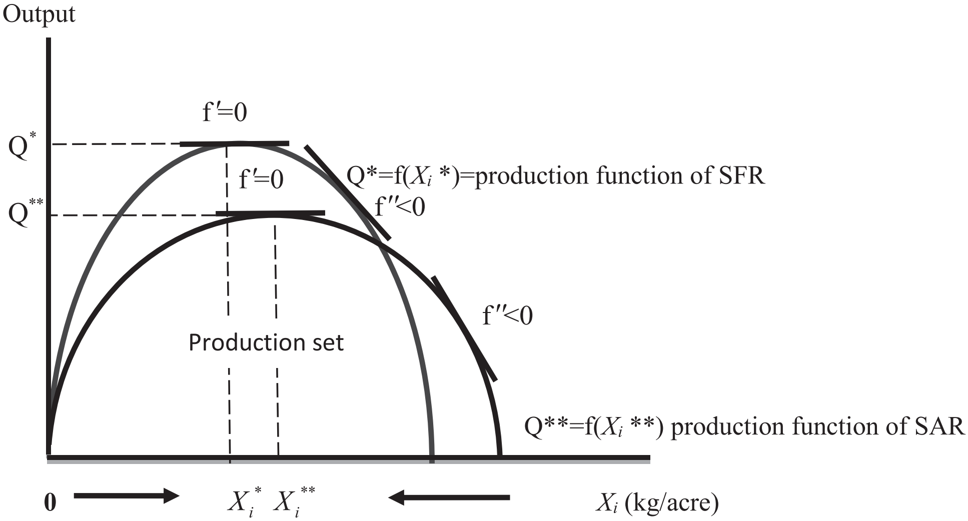

Figure 1: Production set of X_i and Q (kg/acre) (Prepared by the authors)

Points (X_i *, Q*) or (X_i **, Q**) in the production set imply that it is technologically possible to produce Q* or Q** amount of paddy if we apply X_i * or X_i ** amount of inputs in both the salinity free region (SFR) and the salinity affected region (SAR). The production set shows the possible technology choices facing a farm. The function describing the boundary of this set is known as the production function. It measures the maximum possible output Q that we can get from a given amount of X_i. The main objective of the simulation of this study is to identify the physical average level of per acre inputs and paddy production. If the observed physical average level of per acre inputs is higher than the required physical average level of per acre of inputs, farmers should use fewer amounts of inputs and vice-versa. It is strongly argued that the simulation process will be able to answer our research questions through the proposed regression model.

4. Research Methodology

4.1 Study Area

The study area is located in the southwest coastal region of Bangladesh. 27 villages 22 unions under 13 Upazilas of Khulna, Satkhira, and Bagerhat districts are the study sites of the study where the rainy season is hot and humid. Coolness and dryness are the main characteristics of the winter season. The summer is also hot and dry interrupted by occasional heavy rainfall. Salty clay or clay in texture is the common characteristic of soil. When the salty land dries, it becomes hard, and cracks develop, making tillage operation difficult. Due to the strong presence of salinity, most of the cultivable lands remain fallow during the pre-monsoon (March to early-June) and post-monsoon (October to February). The majority of the land is used for aquaculture (mainly shrimp farming). Paddy is the main crop and it is rare to grow three times a year, especially in the monsoon or rainy season. Location and the geophysical features of this region are identified as (1) there are large numbers of shrimp farms in the region; (2) paddy cultivation is badly affected by salinity; (3) the region is adjacent to the Bay of Bengal with the high population; (4) cyclones, storm surges and waterlogging are the common natural hazards in this region; (5) paddy productivity, life and livelihood are badly hampered by salinity in the region.

The study also considers the salinity free northwest region (Pabna district as a bench case) to compare its productivity of paddy status with the salinity affected southwest coastal region. Pabna is located between latitude 23°55′33.4″ *N* to 24°11′24.5″ *N* and longitude 89°02′40.0″ *E* to 89°31′27.4″ *E*. The bench case region has been selected because (1) it is free from shrimp cultivation and unwanted salinity condition; (2) it is not geographically close to the coastal region of Bangladesh; (3) it is not an island, hilly, or a geographically exotic district; (4) paddy, jute, wheat, and other cash crops are grown well in this region and it has three crop rotation a year; and (5) the regional gross domestic product (RGDP) of Pabna is highly dependent upon paddy production. Figure 2 shows the study area of this study.

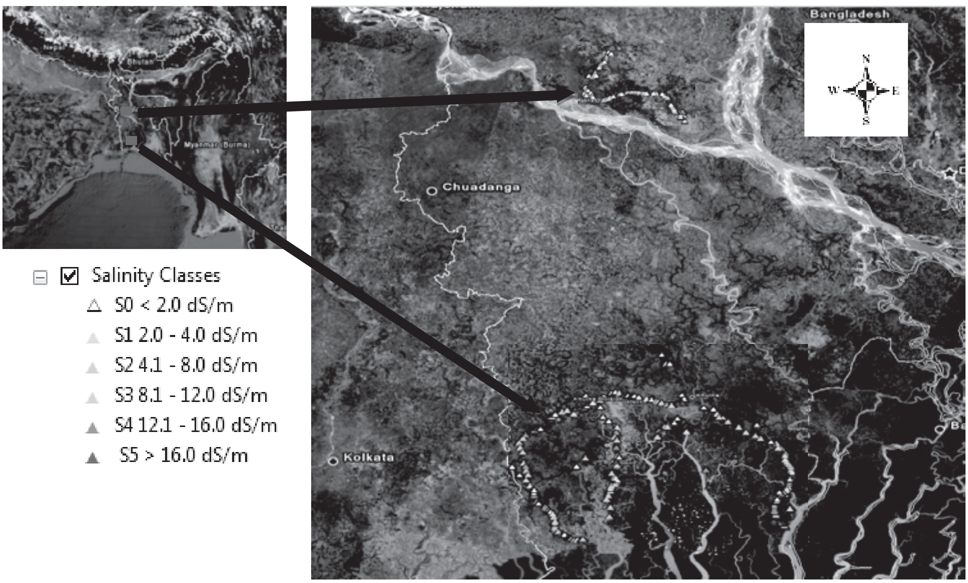

Figure 2: Study Area (Prepared by the authors based on GPS and salinity data)

4.2 Research Approach

Sampling Techniques and Data Collection

The empirical investigations of this study have been undertaken in two ways. The first part comprised a pre-test or a mini version of a full-scale study to observe and understand the current situation of salinity and its impact on paddy production and the second part was consisted of a questionnaire survey. The first part was covered by a discussion with the local paddy farmers of the study area to get ideas and concept buidling of salinity and paddy productivity-related issues in the southwest coastal region of Bangladesh. The second part consisted of a pre-test and questionnaire survey. Before the survey, a pre-test was conducted in March 2018 in few selected villages of the study area which covers 12 respondents for the interview to test and amend the questionnaire for appropriate, required, and relevant information about relevant inputs and paddy production scenario under the salinity condition. After ensuring the appropriateness of the questionnaire, the full-scale survey was conducted through the open-ended questionnaire. This open-ended questionnaire has three segments- information on the survey time, area and respondents' residential address (e.g., village name, word/mouza no, Union, Upazila, District and respondents' phone number and name), respondents' general information (e.g., respondents' age, years of schooling, farm size, family composition and source of income) and paddy production- related information (landowner status, cost, and income from paddy in a year, the yearly production of paddy from different species, hired labor and amount of fertilizer for paddy cultivation in a year and irrigation and salinity related information).

We exclusively identified the heads of the farm households because of their role play in decision making. Input (such as labor, triple superphosphate, and urea), natural shock (salinity), and output (such as Aus, Aman, and Boro) data were collected from paddy farmers who grew paddy in all the three seasons and the level of salinity of their paddy farms was measured by salinometer. For the proper empirical investigation, the researchers used purposive sampling because of its suitability to a target network or a particular community like paddy farmers. This sampling is an approach with a purpose where a researcher or investigator wants to have access to a particular subset of people say paddy farmers and select them randomly for the interview (Tongco, 2007). Following the guideline of the purposive sampling technique and considering only the paddy farmers, this study used random sampling to determine the sample size (paddy farmers). This sampling technique helps to develop generalized findings applicable to all salinity affected paddy farmers. Under this sampling approach, 715 paddy farmers in the salinity affected southwest region and 511 paddy farmers in the salinity free northwest region were selected. Salinity (dSm^{-1}) samples were taken from the respondents' paddy farms at the time of the survey. The survey was completed by ten data collectors, who were active in the selected villages of the 35 (22 in the southwest and 13 in the northwest) unions. The survey was undertaken during September 2018 and February 2019. No proxy data were considered in the study for monsoon paddy. Long year data for salinity could have justified the results better because salinity is a dynamic entity. But it was not possible to cover a greater range of salinity affected areas due to time constraints, funds, and logistic supports. The fieldwork time was short for conducting detailed research and no institutional funding was available because of the status of personally funded research work.

To tackle the resulting bias from purposive sampling, the survey was conducted by a research team with the assistance of ten trained and paid data collectors. All data collectors were collected from the educational institutions of the study area. All respondents (paddy farmers) have been briefed the impacts of salinity on paddy production and the role of the optimum amount of essential inputs for paddy production under the salinity condition. The data collectors did not indulge in any personal and irrelevant gossiping to avoid anchoring or influencing the answers of the respondents.

Model Specification and Diagnostic Test

The translog production function provides a greater variety of substitution and marginal possibilities. We can write the translog production function as:

$$lnY_i = \beta_0 + \sum_{i=1}^{n} \beta_i lnX_i + \frac{1}{2}\left\{ \sum_{i=1}^{n}\sum_{i=1}^{n} \beta_{ii} lnX_i lnX_j \right\} + \sum_{i=1}^{n} \lambda_s lnS_s \quad (7)$$

where lnY_i is the natural log of a value of per acre paddy production; lnX_iX_j indicates the natural log of i^{th} and j^{th} inputs use and lnS_s is the natural log of level of salinity. Salinity is a natural shock and farmers have no control over the salinity. Thus, salinity *(dSm^{-1})* is associated with other inputs and takes additive form in the production function.

The study calculates the elasticity of output by taking the partial derivative of paddy cultivation to the required factors of paddy production. Following this procedure, this study can also derive the elasticity of salinity (S) as it is associated with paddy cultivation:

$$\varepsilon = \frac{\delta InY}{\delta lnS} = \lambda_s \quad (8)$$

The marginal productivity of salinity can be written as

$$\rho = \frac{\delta Y}{\delta S} = \frac{\delta InY}{\delta lnS} * \frac{Y}{S} = \varepsilon \frac{Y}{S} \quad (9)$$

In the study, we proposed the following variables, their description along with measurement units and their hypothesized relationship with the outcome variable (see Table 1 for more details).

Table 1: Description of Variables

Variable	Definition	Unit	Data type	Hypothesized relationship
Lnaus	Sown & harvested in the pre-monsoon & monsoon seasons.	Tk./acre	Continuous	Dependent variable
Lnaman	Grown & harvested in the monsoon & post-monsoon seasons.	Tk./acre	Continuous	Dependent variable
Lnboro	Sown & transplanted in winter & harvested at the end of pre-monsoon season.	Tk./acre	Continuous	Dependent variable
Lntsp	Triple Super Phosphate is an inorganic but used as a base fertilizer improves plant roots.	Tk./acre	Continuous	±
Lnurea	Urea is an inorganic fertilizer that improves the protein metabolism of the plant.	Tk./acre	Continuous	±
Lnlabor	Labor is the fundamental factor required for every production.	man/acre	Continuous	+
Lnsalinity	Salinity is the presence of salts e.g., sodium, chloride, magnesium, sulfates, calcium, and bicarbonates in soil and water.	dSm^{-1}	Continuous	-

Note. 1 US$ = 82 Tk. (Bangladeshi currency)

For a robust basis, we conducted few diagnostic tests such as the collinearity test by the variance inflation factor (VIF), homogeneity of variance test by the Levene statistics, and normality test by Kolmogorov-Smirnov (K-S) test. We used Eviews version 6 and SPSS version 24 econometric software to estimate the parameters of the regression models and run the diagnostic tests.

5. Estimation and Discussion of Results

5.1 Salinity Free Aus, Aman, and Boro Paddy Models

The study first estimates the factor share of the salinity free paddy model (Equation 7). Before imposing assumptions, the coefficient restrictions are tested by the Wald test to confirm asymptotically how much the data set fits these restrictions. All the results from the diagnostic tests make a guarantee that all the collected data and explanatory variables from the salinity free northwest region (Pabna district) are perfectly satisfied with normality test ($P > 0.10$), homogeneity of variance test ($P > 0.10$), and multicollinearity test (maximum VIF of all variables is recoded at 1.173 and minimum VIF of all variables is recorded at 1.006). As shown in Table 2, all variables are significant except a few variables of all paddy varieties at the convenient 1%, 5%, or 10% levels of significance. Further, an increase in urea and TSP or doubling the amount of urea and TSP will lead to a decrease in all varieties of paddy production (because of concavity condition of production function) except urea on aman paddy. The estimated value of labor maintains a hypothesized relationship but it is not possible to keep say anything about the contribution of the labor force to all varieties of paddy production in the salinity-free Pabna district. The insignificant of labor can be understood as the improper utilization of labor in the salinity free area. The main reason is that most of the labor force comes from the paddy farmers' household. Besides, labor scarcity is a common problem in this region. This argument is supported by field survey information. Generally, family-supplied laborers are employed voluntarily and they are considered unskilled compared to the hired labor. Based on the estimated results, we cannot say anything about the impact of salinity on all varieties of paddy production. It is because the crop farms are not affected largely by salinity. The values of Pseudo R-squared (goodness of fit) of 0.540298, 0.583774, and 0.599771 imply that 54%, 58%, and 59% of the total variation in the outcome variables (Aus, Aman, and Boro) can be explained by the variation of explanatory variables.

Table 2: Parameters Estimate of Salinity Free Aus, Aman. and Boro Paddy Models

		Aus model	Aman model	Boro model
Variable	Parameter	Estimates	Estimates	Estimates
	β_0	4.479223***	6.197348***	8.923175***
		(1.799930)	(2.631383)	(1.563043)
ln Urea	β_U	0.182520*	0.468275***	1.410184***
		(0.448036)	(0.642561)	(0.324872)
ln TSP	β_T	0.157826**	0.059151***	0.202367***
		(0.170946)	(0.249615)	(0.232791)
ln Labor	β_L	0.413194	0.205251	0.631670
		(0.828171)	(1.275072)	(0.863364)
$(\ln \text{Urea})^2$	β_{UU}	-0.089802***	-0.012858*	0.158260***
		(0.029417)	(0.041490)	(0.031974)
$(\ln \text{TSP})^2$	β_{TT}	-0.051803*	-0.116088***	-0.081855*
		(0.038065)	(0.045980)	(0.049813)
$(\ln \text{Labor})^2$	β_{LL}	-0.137576	-0.167063	-0.037630
		(0.122114)	(0.188266)	(0.136673)
(ln Urea)*(ln TSP)	β_{UT}	-0.062886***	-0.162688***	-0.019737
		(0.026157)	(0.055587)	(0.036324)
(ln Urea)*(ln Labor)	β_{UL}	0.095492	0.293142*	0.302735***
		(0.147924)	(0.185348)	(0.118652)
(ln TSP)*(ln Labor)	β_{TL}	0.028302	0.162345***	0.103611**
		(0.051041)	(0.057507)	(0.061967)
Salinity	β_S	-0.337161	0.625334	0.737193
		(0.268628)	(0.304374)	(0300923)
Pseudo R-squared		0.540298	0.583774	0.599771
Number of observations (*n*)		511	511	511

Note. Robust standard errors in parenthesis; ***P<0.01, **P<0.05 and *P<0.1 indicate 1%, 5% and 10% level of significance

Source: Authors' calculation based on field survey data 2019

5.2 Salinity Affected Aus, Aman, and Boro Paddy Models

Following the same estimation process of the salinity free paddy model, the study first estimates the factor shares of the salinity affected paddy model (Equation 7). Like the previously estimated result of the salinity-free paddy model, all variables are significant except a few at the convenient 1%, 5%, or 10% level of significance and show the expected hypothesized relationship (see Table 3 for more details). Like the collected data and explanatory variables from the salinity free region, all the collected data in salinity affected southwest coastal regions are valid and reliable because all of the explanatory variables are satisfied with the normality test, homogeneity of variance test, and multicollinearity test.

In the salinity affected southwest coastal region, TSP and labor exert positive impacts on all varieties of paddy production. Like the TSP and labor, fertilizer urea is statistically significant, but it is negatively related to all varieties of paddy. The negative relationship between urea and paddy production in the salinity affected coastal area implies that most of the paddy farmers do not apply the appropriate or recommended dose of urea in the growing stage of paddy.

Further, an increase in TSP and labor or doubling the amount of TSP and labor will lead to a decrease in all varieties of paddy production. At this stage, production cost will be maximized and the paddy farmer will be looser to cultivate paddy. Another finding from the estimated result reveals that paddy farmers get more production if they double the amount of urea at the production stage. Based on the intercept of different paddy models, it is said that Aus and Boro are vulnerable paddy varieties to salinity. The values of Pseudo R-squared (goodness of fit) of 0.475869, 0.287205, and 0.612332 imply that 47%, 28%, and 61% of the total variation in the outcome variables (Aus, Aman and Boro) can be explained by the variation of explanatory variables.

Table 3: Salinity Affected Aus, Aman, and Boro Paddy Models

		Aus model	Aman model	Boro model
Variable	Parameter	Estimates	Estimates	Estimates
	β_0	2.064458***	9.766713***	4.743198***
		(2.887840)	(1.243766)	(1.353471)
ln Urea	β_U	-0.695450**	-0.109069***	0.154111***
		(0.712528)	(0.341161)	(0.874755)
ln TSP	β_T	0.937989***	0.325787**	0.092015***
		(0.534879)	(0.164621)	(0.170341)
ln Labor	β_L	0.407764***	0.516401***	0.245898***
		(0.712528)	(0.656043)	(0.399826)
$(\ln Urea)^2$	β_{UU}	0.125260*	0.066296***	0.192883***
		(0.118032)	(0.031437)	(0.173510)
$(\ln TSP)^2$	β_{TT}	-0.154895***	-0.212500***	-0.056085
		(0.164621)	(0.150978)	(0.064234)
$(\ln Labor)^2$	β_{LL}	-0.744306***	-0.243268***	0.175853***
		(0.259911)	(0.111793)	(0.084542)
(ln Urea)*(ln TSP)	β_{UT}	0.266908**	0.065758*	0.038413***
		(0.151338)	(0.044304)	(0.200791)
(ln Urea)*(ln Labor)	β_{UL}	0.600448***	0.115489	0.552923***
		(0.295729)	(0.116447)	0.159015
(ln TSP)*(ln Labor)	β_{TL}	-0.033283	-0.055928	0.158399***
		(0.097070)	(0.054688)	((0.064251)
Salinity	β_S	-0.857967***	-0.287511***	-0.782011**
		(0.150324)	(0.135760)	(0.101923)
Pseudo R-squared		0.475869	0.287205	0.612332
Number of observations (*n*)		715	715	715

Note. Robust standard errors in parenthesis; ***P<0.01, **P<0.05 and *P<0.1 indicate 1%, 5% and 10% level of significance

Source: Authors' calculation based on field survey data 2019

Estimated parameters of salinity free and salinity affected aus, aman, and boro paddy models in Table 2 and 3 are not yield identical results and signs and fail to maintain the hypothesized relationship because of the different levels of salinity in the paddy farms. For example, TSP and Urea can play an important role to increase all varieties of paddy production in the salinity free northwest region. They maintain the concavity condition of production function and cross-effect in certain paddy species. On the contrary, TSP, Urea, and labor have a significant role to increase paddy production in the salinity affected southwest coastal region and maintain the concavity condition and cross-effect in a few paddy varieties. But Urea fails to keep the expected sign and hypothesized relationship with paddy production in the salinity affected region because of the inverse relationship between salinity and Urea. It is generally known that Urea cannot be effective in the salinity affected crop farm after its immediate application (Karandish and Šimůnek, 2018; Gulab et al., 2019). One year of the lag of urea can change this relationship positive (Rahman and Anik, 2020; Liu et al., 2020).

5.3 Marginal Return

We calculate the marginal return from the parameters of the models and their concern elasticities which is depicted in Table 4. The marginal return from urea, TSP, and labor plays an important role to increase different varieties of paddy in the salinity free northwest region. For example, one percent increase in expenditure on urea will lead to an increase in Aus, Aman and Boro paddy by 9.36kg, 23.88kg, and 76.28kg respectively when other things remain constant. This proposition is also true in the salinity affected coastal region.

Table 4: Marginal Returns of Input

Variable	Marginal return (salinity free northwest region)			Marginal return (salinity affected southwest region)		
	Aus	Aman	Boro	Aus	Aman	Boro
Urea	9.36	23.88	76.28	40.16	6.58	8.92
TSP	39.95	11.58	45.77	25.53	88.22	18.26
Labor	37.11	18.98	23.38	23.76	34.54	14.78

Source: Authors' calculation based on field survey data 2019

5.4 Simulation of Average Inputs and Paddy Production

We can estimate the physical values of the required inputs and output by the simulation process. For better understanding, we only estimate per acre average TSP and paddy because of the significant values of TSP in both salinity free and salinity affected Aus, Aman, and Boro paddy models. Under the same procedure, we can also estimate the physical values of urea, and labor.

The observed average levels of per acre TSP for Aus, Aman, and Boro paddy are 7.42 kg, 10.12 kg, and 9.47 kg respectively. These are I50 kg for Aus, 52 kg for Aman, and 58 kg for Boro paddy when we consider the simulated physical average level of per acre TSP. On the other hand, the observed average levels of per acre TSP for Aus, Aman, and Boro paddy are 5.22 kg, 5.47 kg, and 4.16 kg in the salinity affected southwest coastal region at salinity level *(dSm^{-1})*. Whereas, the simulated physical average levels of per acre Aus, Aman, and Boro paddy are 152 kg, 172 kg ,and 184 kg at the same level of salinity. Recently, Bangladesh Rice Research Institute (BIRI) has been able to invent salt tolerant paddy varieties at this salinity level. But most of the paddy farms in the southwest coastal region possess the highest level of salinity and it hampers the productivity of paddy at Aus and Boro season. Our findings also support this statement. Our findings from estimated results reveal that the average levels of per acre TSP in Aus, Aman, and Boro paddy are 8 kg, 6.66 kg, and 5 kg respectively. Whereas the simulated physical average levels of per acre TSP for Aus, Aman, and Boro paddy are recored at 185 kg, 198 kg, and 215 kg respectively (see Table 5 for more details).

Table 5: Summary Statistics of Simulated Average Level of Per Acre TSP and Paddy Production

Region	TSP and paddy production (kg/acre)					
	Aus		Aman		Boro	
	TSP	Yield	TSP	Yield	TSP	Yield
Salinity free region	$\bar{T}^{*}=50$ $\bar{T}=7.42$	$\bar{Q}^{*}=1891$ $\bar{Q}=1878$	$\bar{T}^{*}=52$ $\bar{T}=10.12$	$\bar{Q}^{*}=1959$ $\bar{Q}=1958$	$\bar{T}^{*}=58$ $\bar{T}=9.47$	$\bar{Q}^{*}=2162$ $\bar{Q}=2142$
Salinity affected region Salinity level (≤ 8.0 dS/m)	$\bar{T}^{**}=152$ $\bar{T}=5.22$	$\bar{Q}^{**}=1348$ $\bar{Q}=1334$	$\bar{T}^{**}=172$ $\bar{T}=5.47$	$\bar{Q}^{**}=1833$ $\bar{Q}=1826$	$\bar{T}^{**}=184$ $\bar{T}=4.16$	$\bar{Q}^{**}=1487$ $\bar{Q}=1444$
Salinity affected region Salinity level (≥ 8.1 dS/m)	$\bar{T}^{**}=185$ $\bar{T}=8$	$\bar{Q}^{**}=1310$ $\bar{Q}=1289$	$\bar{T}^{**}=198$ $\bar{T}=6.66$	$\bar{Q}^{**}=1834$ $\bar{Q}=1791$	$\bar{T}^{**}=215$ $\bar{T}=5$	$\bar{Q}^{**}=1403$ $\bar{Q}=1376$

Note. The upper value indicates the simulated physical average level of per acre TSP and paddy varieties.
The lower value indicates the observed average level of per acre TSP and paddy varieties.

Source: Authors' calculation based on field survey data 2019.

6. Conclusion and Policy Implications

Like other second-generation climatic problems (sea-level rise and intensity of droughts), salinity generates a negative impact on paddy cultivation and badly hampers food security and coastal livelihoods. All paddy varieties are not equally vulnerable to salinity. Aus and boro paddy are mostly affected by salinity. As a rain-fed variety, Aman paddy is less affected by salinity. Salinity is a natural hazard or climatic shock, so paddy farmers have no control over the salinity. Coping with this salinity intrusion condition, it requires some adaptive techniques such as fertilizer selection, the appropriate dose of essential fertilizer, required labor, selection of salinity tolerance rice varieties, and know the level of salinity, and soil quality. Proper application of fertilizer and labor has significantly increased paddy production in the salinity affected region. But in reality, the paddy farmers of the salinity affected southwest coastal region use the least amount of fertilizer and fail to gain more return from paddy production. Thus, the paddy farmers should give more importance to the usage of the appropriate amount of required fertilizer to produce paddy. Farmers should cultivate high yielding salt-tolerant varieties of aus and boro paddy that can ensure sustainable paddy production. The government intervention is highly required to change the decision of the farmers regarding input pattern by providing more subsidies on essential fertilizer of paddy.

The study fully depends on the cross-sectional data for empirical assessment. But we cannot certainly say that our study is free of certain flaws. The study warranted a systematic investigation of the impact of salinity on paddy production and accessed the contribution of major inputs to paddy production under the salinity present condition. Due to the lack of proper logistic support, time constraint, not the usage of one year lag variable, and longitudinal data, it may narrow down the scope to get robust findings. However, we conducted several diagnostic tests to check the validity and reliability of the study findings.

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