Nexus between Salinity and Ecological Sustainability of Crop Production of Southwest Coastal Region of Bangladesh: Approach of Translog Production Function

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ABSTRACT

Climate change due to global warming and its negative consequence on environment and agro ecosystem is a threat of the coastal economy. Increased frequency of heavy precipitation events, increase in drought, increase in intense tropical cyclones, sea-level rise, and increase in temperature are the major aspects of climate change and mostly relevant to coastal regions. Most of these factors are responsible for creating salinity in the coastal region. Salinity is the common phenomenon of any coastal region and southwest coastal region of Bangladesh is not free from such type of natural hazard. The impacts of salinity are consider as one of the most serious threats to the environment with its potential negative impacts on food security, agriculture, fisheries, human health, ecology, soil degradation, infrastructure, coastal agrarian economy, water and other natural resources. The scientific results of global climate modeling of the year of commonly 2100 reveals that degradation of productive land, loss of farm production, diminished farm production, and damage to infrastructure are also affected by the existence of high level of salinity. Salinity has been increasing over period of time of southwest coastal region of Bangladesh and 0.223 million ha (26.7%) of total cultivated land is affected by various degree of salinity and badly hampered in the crop ecology and it is now threaten in calorie intake and food security. This study carried out through questionnaire survey in the salinity prone areas of southwest coastal region of Bangladesh and attempts to assess the impact of salinity on crop ecology. Due to increased salinity, the crop production has been reduced over the past three and a half decades in the southwest coastal region of Bangladesh. As a result, per capita income falls, and limited access to food diffuses over the rural livelihood and makes pressure on regional agrarian economy. Through collected household micro-cross section data, Translog (Transcendental logarithmic) production function linked to salinity issues and crop ecology, this paper identifies the negative impact of salinity on crop ecology and suggests a composite adaptation policy issues to cope with this unexpected salinity intrusion in the southwest coastal region of Bangladesh.

Keywords: Salinity, Crop production, Southwest coastal region, Bangladesh.

JEL Classifications: D13, O13, Q12, Q57, R14

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1. Introduction

Climate change due to global warming and its negative consequence on environment and agro ecosystem is a threat of the coastal economy. The Intergovernmental Panel on Climate Change (IPCC, 2007) predicts an increased frequency of heavy precipitation events, drought, intense tropical cyclones, sea level rise (SLR) and temperature. All those aspects related to climate change are very relevant to coastal regions. Most of these factors are responsible for creating salinity in the coastal region. Salinity is the common phenomenon of any coastal region and Bangladesh coast is not free from such type of natural hazards.

The impacts of salinity are considered as one of the most serious threats to the environment with its potential negative impacts on food security, agriculture, fisheries, human health, biodiversity, water, and other natural resources. Degradation of productive land, loss of firm production, diminished farm production, and damage to infrastructure are also affected by the existence of salinity. In total, 52.8% of the cultivable land in the coastal region of Bangladesh was affected by salinity in 1990 (Karim et al., 1990) and the salt affected area has increased by 14600 ha per year (SRDI[1], 2001). SRDI had made a comparative study of the salt affected area between 1973 to 2009 and showed that about 0.223 million ha (26.7%) of new land has been affected by varying degrees of salinity during the last four decades and that has badly hampered the agro-biodiversity (SRDI, 2010). Figure 1.1 illustrates the salinity intrusion scenario of different years of the coastal region of Bangladesh.

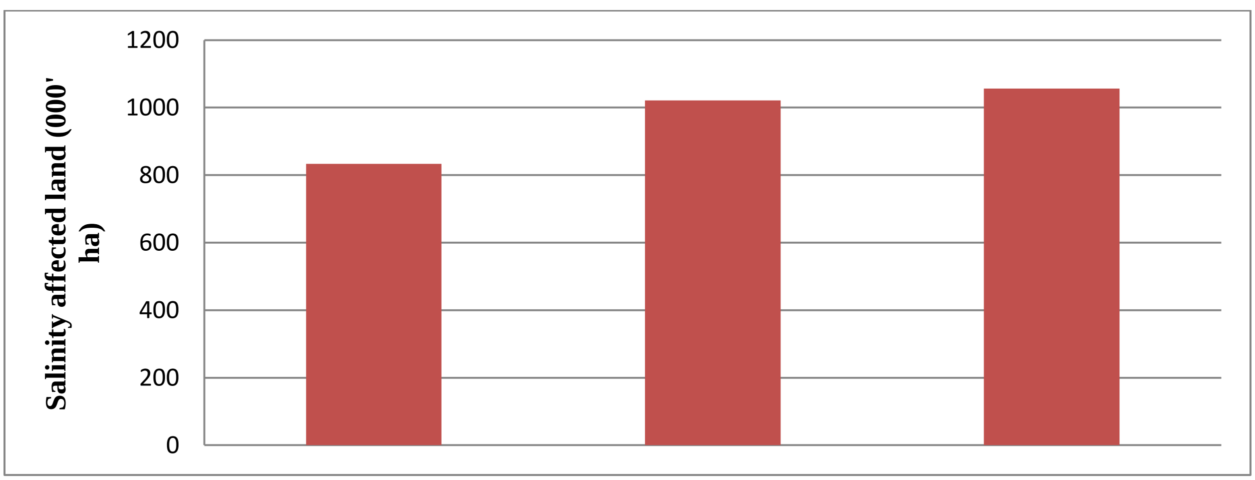

Figure 1.1. A comparative study of the salt affected area for the years 1973, 2000, and 2009 of the coastal region of Bangladesh (SRDI, 2010).

[1] SRDI stands for Soil Resource Development Institute.

Most of Bangladesh's coastal region lies on the southwest coastal region of the country. Approximately 30% of the crops land of Bangladesh is located in this region (Mondal, et al., 2001) and continuous to support crops productivity and GDP growth. But in the recent past, the contribution of crops to GDP has decreased because of salinity. Out of 2.68 million ha of coastal and off-shore lands, about 1.056 million ha of arable lands are affected by varying degrees of salinity (SRDI, 2010). Farmers mostly cultivate low yielding, traditional rice varieties. Most of the land kept fallow in the summer or pre-monsoon hot season (March-early June) and autumn or post-monsoon season (October-February) because of soil salinity, lack of good quality irrigation water and late draining condition. In the recent past, with the changing degree of salinity of southwest coastal region of Bangladesh, rice production becomes very risky and crop yields, cropping intensity, production levels of rice and people's quality of livelihood are much lower than that in the other parts of the country. As limited resources with high population, farmers have no scope to keep her land fallow. So, it is crucial matter to consider high salinity tolerance instead of vulnerable crops to salinity that ensures calorie intake, food security, poverty reduction, and economic growth.

There are large numbers of existing peer-reviewed studies considered the salinity of whole coastal region of Bangladesh and its impact on ecology or agro-biodiversity. But the level of intensity of salinity is not homogeneous or similar to all of coastal Bangladesh and it is essential to require different adaptation policies for different salinity levels of different coastal regions of Bangladesh. This study focuses only the specific coastal region (southwest coastal region) of Bangladesh. This study also quantifies the impacts of salinity on different crops production in this coastal region and develops the necessary adaptations options.

The specific objective of this study is to identify the highly tolerance crops to salinity and develop an approach for the management strategy to produce more crops under the salinity intrusion condition of southwest coastal region of Bangladesh.

2. Materials and methods

2.1 Study area

Soil salinity is more hazardous in the southwest coastal region than the other coastal region of Bangladesh. Most crops land of this part is in under threaten due to high level of salinity. This study has selected the site in Khulna, Satkhira, and Bagerhat districts as a study area located in the southwest coastal region of Bangladesh. This region is part of an active delta of large Himalayan Rivers and is vulnerable to natural hazards due to its disadvantaged geographic location, and its flat and low-lying topography[2]. This study site is located between latitude from $22^{0}16'00.3''$ N to $22^{0}58'56.2''$ N and longitude from $88^{0}58'01.1''$ E to $89^{0}56'00.7''$ E of southwest coastal region. The site is bounded by the Ganges River in the North, tributaries from the Meghna River in the East, an international boundary in the West, and the Bay of Bengal in the South (see Figure 3.2 for more details).

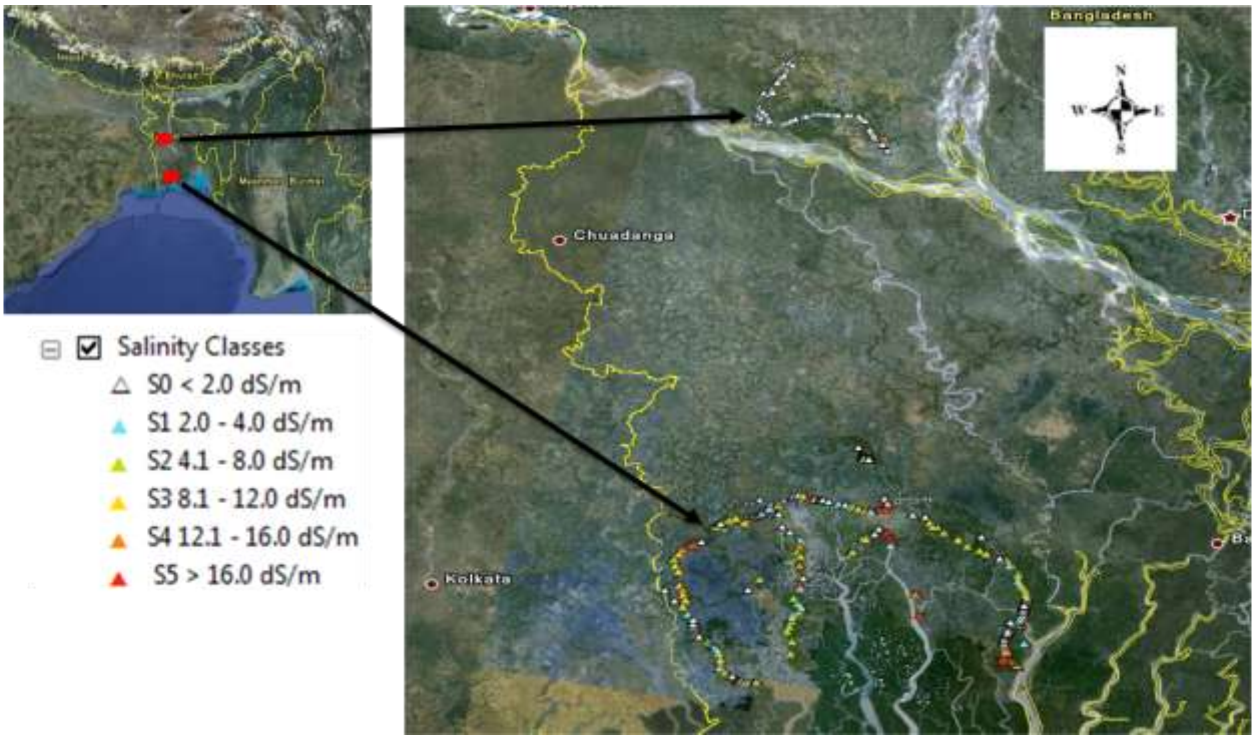

Figure 2.1. Study area (southwest coastal region) of Bangladesh
(Source: Prepared by the author based on GPS and EC (dS/m) data)

The whole coastal region of Bangladesh has been suffering salinity related problems for many years. But the salinity problem in the southwest coastal region is more severe due to the following reasons:

1. This region has excessive shrimp culture.
2. This region possesses strong intensity of water and soil salinity.

[2] Source: www. pravdabangladesh.wordpress.com; Kibria, 2011

3. This region is adjacent to the Bay of Bengal with high population density and highly degraded soil by salinity.
4. Tidal waves, storm surges and cyclones frequently hits and bring salinity from the Bay of Bengal.

2.2 Sampling, Field survey, and data collection

To represents the population as a whole, a complete and accurate the sample framework is necessary. In this study the sample frame is a set of different crops producing farmers, depending on farming system, and the level of salinity (dS/m). This study followed the purposive sampling methods to collect household micro cross-section data from crops farmers.

The economic agent and sample unit 'household' was chosen because production decisions come from the household level, rather than at the individual level. To obtain salinity level (dS/m) and crops production data, southwest coastal region was visited two times from 7 September 2012 to 30 September, 2012 and from 3 February, 2013 to 10 February, 2013. 317 respondents (crops farmers affected by salinity) were selected from salinity affected southwest coastal region. Latitude, longitude, and salinity data were collected by using Germin (GPS map 62 series) and a salinometer.

Selected characteristics of the heads of the sample households, the overwhelming majority of whom were male, are presented in Table 2.1. As many as 67.82 percent of the sample household were engaged in active farming activities and 32.18 percent of the sample households were engaged in casual farming activities in the salinity affected southwest coastal region. In addition, small trading, remittance, service, shrimp farming are the alternative sources of income of sample households in this region.

2.3 The analytical approach

To study the impacts of salinity on crops, Translog production function was used because of its advantage over the other production function. Translog production function is a generalization of the Cobb-Douglas production function. It is linear in parameters and can be estimated using least square method (Blackorby and Russell, 1989). In addition, Translog production function can easily explain the cross and marginal effects of inputs. This study has considered cotton, wheat and three varieties of rice (Aus, Aman, and Boro) under the salinity intrusion condition. Crops production depends on many factors. But this study has only considered crops production as a function of urea, TSP, phosphorus, green manures, and labor as the input factors and salinity as the natural shocks. Urea, TSP, phosphorus, green manures, and labor are considered man-controlled variables or decision variables and salinity is considered as a natural phenomenon and farmer has no control over the salinity. An increase in the level of one of the man-controlled variables results in a change (increasing or decreasing, depending on the relationship) in the level of the dependent variable up to a certain point. Any further increase in its level results in an opposite response (decrease or increase, respectively) in the dependent variable (Dinar, 1991). Other factors (tillage, irrigation, pesticides, weeding, drought, precipitation, etc.) affecting the crops production are assumed to be constant in this study. The implicit relationship of crops production and its inputs and shock is:

$$Q=f(U,T,P,G,L,S) \tag{1}$$

where, Q=quantity of output, T=TSP, P=phosphorus, G=green manures, L=labor, and S=salinity. Due to the presence of a climatic induced factor (salinity) in the southwest coastal region, this study assume that urea, TSP, phosphorus, green manures, and labor are weakly separable from salinity. This means that marginal rate of substitution between urea-TSP ($MRTS_{UT}$), urea-phosphorus ($MRTS_{UP}$), urea-green manures ($MRTS_{UG}$), urea-labor ($MRTS_{UL}$), TSP-phosphorus ($MRTS_{TP}$), TSP-green manures ($MRTS_{TG}$), TSP-labor ($MRTS_{TL}$), phosphorus-green manures ($MRTS_{PG}$), phosphorus-labor ($MRTS_{PL}$), and green manures-labor ($MRTS_{GL}$)are independent from salinity. Based on the weakly separable condition, equation (1) can be written as:

$$Q=F[f(U,T,P,G,L);S] \tag{2}$$

This study also assumed that urea, TSP, phosphorus, green manures, labor and salinity are homothetic in their components. Mathematically,

$$Q=F\left[f\left\{U(U_1,U_2,L\ ,U_i),T(T_1,T_2,L\ ,T_j),P(P_1,P_2,L\ P_k),G(G_1,G_2,L\ ,G_l),L(L_1,L_2,L\ ,L_m)\right\};S(S_1,S_2,L\ ,S_e)\right] \tag{3}$$

Including interaction terms in the log natural liner production function improves empirical fit and allows pairs of factors to be complements or substitutes in production. Translog production function plays an important role in this regard. Translog production function developed by Christensen, Jorgensen, and Lau in 1973 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). Translog production function is an attractive flexible function. This function has both liner and quadratic terms with the ability to use more than two factors inputs. This function can be approximated by second order Taylor series (Christensen et al., 1973). Translog production function used in salinity free rice production can be written in terms of log natural form as

$$\ln(Q_i) = \beta_0 + \sum_{j=1}^{N} \beta_j \ln(x_{ij}) + 0.5 \sum_{j=1}^{N} \theta_j \ln(x_{ij}) \ln(x_{ij}) + \sum_{j\neq k}^{K} \gamma_j \ln(x_{ij,t}) \ln(x_{ki}) + s_i + \mu_i \tag{4}$$

where, subscript of variables indicates the used inputs for urea, TSP, phosphorus, green manures, and labor, and subscript of salinity (s_i) indicates the level of salinity, and μ_i indicates stochastic disturbance or error term with mean zero and variance σ^2. Factor shares for urea, TSP, phosphorus, green manures, and labor of crops production of equation (4) is given as

$$\theta_u = \frac{\partial \ln Q}{\partial U} = \beta_U + \beta_{UU}\ln U + \beta_{UT}\ln T + \beta_{UP}\ln P + \beta_{UG}\ln G + \beta_{UL}\ln L \quad (5)$$

$$\theta_T = \frac{\partial \ln Q}{\partial T} = \beta_T + \beta_{TT}\ln T + \beta_{TU}\ln U + \beta_{TP}\ln P + \beta_{TG}\ln G + \beta_{TL}\ln L \quad (6)$$

$$\theta_P = \frac{\partial \ln Q}{\partial P} = \beta_P + \beta_{PP}\ln P + \beta_{PU}\ln U + \beta_{PT}\ln T + \beta_{PG}\ln G + \beta_{PL}\ln L \quad (7)$$

$$\theta_G = \frac{\partial \ln Q}{\partial G} = \beta_G + \beta_{GG}\ln G + \beta_{GU}\ln U + \beta_{GT}\ln T + \beta_{GP}\ln P + \beta_{GL}\ln L \quad (8)$$

$$\theta_L = \frac{\partial \ln Q}{\partial L} = \beta_L + \beta_{LL}\ln L + \beta_{LU}\ln U + \beta_{LT}\ln T + \beta_{LP}\ln P + \beta_{LG}\ln G \quad (9)$$

The major restrictions imposed on equations (4) is

Symmetric restriction and restriction for Cobb-Douglas production function:

$$\beta_{UT} = \beta_{TU} = \beta_{UP} = \beta_{PU} = \beta_{UG} = \beta_{GU} = \beta_{UL} = \beta_{LU} = \beta_{TP} = \beta_{PT} = \beta_{TG} = \beta_{GT} = \beta_{TL} = \beta_{LT} = \beta_{PG} = \beta_{GP} = \beta_{PL} = \beta_{LP} = \beta_{GL} = \beta_{LG} = 0 \quad (10)$$

Linear homogeneity in factors of production:

$$\sum_{j=1}^{N}\beta_j = \sum_{j=1}^{N}\beta_i = 1; \sum_{j=1}^{N}\beta_{ij} = \sum_{j=1}^{N}\beta_{ji} = 0; \sum_{j=1}^{N} i\beta_{iQ} = 0 \quad (11)$$

3. Results and discussion

This study first estimates the factor shares (equations 5, 6, 7, 8, and 9) of salinity affected crops model. Prior to imposing assumptions, the coefficient restrictions are tested by Wald test so as to confirm asymptotically how much the data set fits these restrictions. After that, this study focuses on the estimation side of the salinity affected Translog production (equation 4). As shown in table 3.1, all variables are significant except a few variables of all crops at the 1%, 5%, and 10% levels and show the expected sign.

Table 3.1. Regression coefficient estimates of different crops under salinity affected soil

Variables	Parameter	Aus rice	Aman rice	Boro rice	Wheat	Cotton
	β_0	3.174557***	7.467213***	5.013768***	9.359871***	10.540871**
ln U	β_U	-1.087231*	-0.901031**	-1.326223**	-0.512390***	0.372454***
ln T	β_T	0.787984***	0.451289*	0.234712***	0.768972***	0.897167***
ln P	β_P	0.490123**	0.340912**	0.560369**	0.679037***	0.912390**
ln G	β_G	0.937983*	0.671230**	0.436750*	0.549038*	0.783038**
ln L	β_L	0.637490***	0.743292***	0.440628**	0.339078***	0.660350**
$(\ln U)^2$	β_{UU}	-0.126702	-0.139800**	-0.195071	0.236512*	0.092091*
$(\ln T)^2$	β_{TT}	-0.078923*	-0.190231*	-0.219012***	0.078920***	0.078923*
$(\ln P)^2$	β_{PP}	-0.085908*	-0.03453	-0.115541	-0.103109***	0.110090**
$(\ln G)^2$	β_{GG}	-0.183421**	-0.229012***	-0.298231*	-1.174502*	-0.313678***
$(\ln L)^2$	β_{LL}	-0.134678	-0.2339031*	-0.137097	-0.097123	-0.231320**
(ln U)*(lnT)	β_{UT}	0.458091*	0.067901**	0.233160***	0.317420***	0.109510***
(ln U)*(lnP)	β_{UP}	0.607123	0.231295*	0.502971***	0.173420**	0.450091*
(ln U)*(lnG)	β_{UG}	-0.013120*	-0.441890**	-0.078213	-0.045671	-0.145531*
(ln U)*(lnL)	β_{UL}	-0.031280***	-0.342098***	-0.512309*	-0.179809***	-0.119091*
(ln T)*(lnP)	β_{TP}	-0.321390*	-0.085671***	-0.330090***	-0.234351***	-0.190834*
(ln T)*(lnG)	β_{TG}	-0.452361	-0.380010	-0.290034***	-0.109230***	-0.070921**
(ln T)*(lnL)	β_{TL}	-0.543296*	-0.278021**	-0.287525	-0.033265	-0.065754*
(ln P)*(lnG)	β_{PG}	-0.112011***	-0.092389**	-0.009350***	-0.032170	-0.348509
(ln P)*(lnL)	β_{PL}	-0.096190	-0.276431**	-0.123780	-0.290125	-0.190930
(ln G)*(lnL)	β_{GL}	-0.243279***	-0.1332189***	-0.462544*	-0.160450*	-0.339087***
S	β_S	-923209***	-0.667891***	-0.729321***	-0.233034***	-0.176540**
R^2		0.474078	0.390050	0.568023	0.579421	0.529070
Number of observation		107	162	129	101	92

*** Significant at the 1% level, ** Significant at the 5% level, and * Significant at the 10% level

A one percent increase in urea induced to reduce per acre Aus rice, Amam rice, Boro rice, wheat, and cotton production by 1.087231, 0.901031, 1.326223, 0.512390, and 0.372454 kg respective in the salinity affected southwest coastal region of Bangladesh. Most of the log natural quadratic forms of inputs of all crops are negative and significant, except urea and TSP of wheat and cotton and phosphorus of cotton, and they support the concavity condition of production. The cross effect of urea-TSP and urea-phosphorus are positive and significant for all crops, which implies that urea-TSP and urea-phosphorus are substitute of each other. Similarly, most of the cases, TSP-Phosphorus, TSP-green manure, TSP-labor, phosphorus-green manure, and green manure-labor are complements of each other under the salinity affected soil. A one percent increase in salinity induced to reduce per acre Aus rice, Aman rice, Boro rice, wheat, and cotton production by 923209, 0.667891, 0.729321, 0.233034, and 0.176540 kg respectively. Based on the estimated intercept, Aus rice and Boro rice has the smaller autonomus production status compare to those of the other three crops and it is suggest that Aus rice and Boro rice are most vulnerable to salinity.

4. Descriptive statistics

The incidence of salinity affects the farmer in resource allocation and resource transformation because of returns from affected soils decline, and this may even lead to abandoning production activities under the presence of high level of salinity (Singh and Singh, 1995). Table 4.1 illustrates total production, total cost, and profit from rice varieties (Aus, Aman, and Boro), wheat, and cotton.

Table 4.1. Per acre yield, income, total cost, and profit of varieties of rice (Aus, Aman, and Boro), wheat, and cotton under salinity intrusion condition

	Rice Varieties			Wheat	Cotton
	Aus	Aman	Boro		
Yield (kg)/acre	725	956	1578	944	360
Income (kg/acre)	13,050	16,650	28,404	23,600	54,000
Total cost (kg)/acre	11,399	14,703	25,675	10,179	31,860
Profit (Tk.)	1651	1947	2729	13,421	22,140
Sowing	Mar-Mid May	Jun-Aug	Nov-Jan	Nov-Dec	1. Oct after monsoon 2. Apr-May
Harvesting	Jul-Aug	Nov-Dec	Apr-May	Mar-Apr	1. Mar 2. Oct-Nov

(Source: BBS, 2010)

Farmers of salinity affected region gets less amount of profit from all rice varieties compare to those of wheat and cotton.

5. Conclusion and policy implications

Salinity is a major natural hazard of the southwest coastal region of Bangladesh. Like other second generation climatic problem (sea-level rise and drought), salinity creates negative impacts on crops production and badly hampered food security and rural livelihood. All crops are not equally vulnerable to salinity. Aus rice and Boro rice are the most affected by salinity. As a rain fed variety, Aman rice is less affected by salinity because rain and flood water washes out and reduces the level of salinity. In addition, wheat and cotton grows moderately well under the high salinity level. Farmer should cultivate high yielding wheat and cotton instead of vulnerable rice varieties (Aus rice and Aman rice) to salinity that could produce sustainable crops yield. Farmers should use more TSP, phosphorus, green manure. Government can induce the farmer's decision to change the input patterns by providing more subsidies on TSP and phosphorus in the southwest coastal region of Bangladesh. This policy will help the farmers to produce more crops with lower production cost.

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