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

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Abstrct *Salinity has been increasing in the coastal region of Bangladesh and 0.223 million ha (26.7%) of total cultivated land affecting the crop ecology. This study uses cross-section data collected by suruey for application of Translog (Transcendental logarithmic) production function to generate empirically supported assessment. Aus rice and Boro rice are mostly vulnerable to salinity than Aman rice, Wheat, and Cotton. Fertilizer plays an important role to control salinity. Use of Urea in salinity intrusion condition is harmful for crop production but use of recommended dose of Phosphorus, TSP, green manures can neutralize the level of salinity and improve the crop productivity under the salinity intruded condition. The findings of this study provide a robust basis for policy makers, researchers, and stakeholders for further research and development of specific policies and plan.*

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

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

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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.

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, 2001). 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 crops instead of vulnerable crops to salinity that ensures calorie intake, food security, poverty reduction, and economic growth.

SRDI stands for Soil Resource Development Institute.

There are large numbers of existing peer-reviewed studies focused on salinity and crop ecology in the world. Land, soil, hydrology, and agro-climatic parameters are the basic components of the coastal ecosystem. Crop production is largely dependent upon the quality and limitations of these natural resources. Rice, jute, sugarcane, cotton, wheat, barley, tomato, spinach, potato, and other crops can be grown under saline conditions, but their contributions to cropping intensity are very low. Salinity is the most dominant limiting factor in the coastal region. It affects certain crops at different levels of salinity and at critical stages of growth reduces yield and causes crop failure. The problem of salinity is a serious constraint for constructing the sustained crop production and makes it difficult to develop a "Green Revolution." Drought, water excess, and salinity badly hampered the grass production in the Netherlands (Kroes and Supit, 2011). The impacts of salinity and water loggings constraints to salt land pasture production in Australia. Dry land salinity is a major problem affecting agricultural production and natural resource value in Australia 5.7 Mha are presently considered as being at risk from salinity because of shallow water tables and this figure is expected to grow to 17 Mha by the year 2050 (Bennett et al., 2009). Soil salinity and water logging directly affects the farmer in resource allocation and resource transformation in northwest India (Singh and Singh, 1995). Irrigated agriculture occasionally suffers from problems related to high levels of salinity in irrigation and soil in the San Joaquin and Imperial Valleys of California (Dinar et al., 1991). Germination and seedlings stages are most sensitive to saline irrigation water, and any failure in this stage will consequently lead to a reduction in crop production (Hamdy et al., 1993). For Bangladesh, there are several studies about the salinity issue. In saline soils, crop growth is hampered by salt accumulation in the crop root zone. If the upward salt movement caused by evaporation exceeds the downward gravitational movement, salt will accumulate in the root zone. Most plants suffer salt injury at concentration equivalent of electrical conductivity of the soil saturation extract (ECe) of 4 dS/m or higher in the coastal region of Bangladesh (Mondal et al, 2001). Increasing salinity and low quality irrigation water are responsible for farmers' being unable to produce more rice and other agricultural crops in the southwest coastal region of Bangladesh (Rahman et al., 2011). However, very few studies focus on the empirically supported assessment of salinity and its impacts on crop productivity in the southwest coastal region of Bangladesh. The severity of salinity in Bangladesh varies throughout the time and regions of Bangladesh and it is essential to review different policies for different salinity levels among the different coastal regions. The southwest coastal region experiences more severe salinity level compared to other coastal regions of Bangladesh and therefore, this region requires different adaptation policies for more crop productivity and ensuring food security. This study focuses on the economic assessment of crop productivity resulting from severe salinity in the southwest coastal region of Bangladesh. 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 crop land of this part is in the process of 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 (Kibria, 2011). This study site is located between latitude from N “22^{0}16’00.3” to N “22^{0}58’56.2” and longitude from E “88^{0}58’01.1” to E “89^{0}56’00.3”of southwest coastal region. The site is bounded by the Ganges River

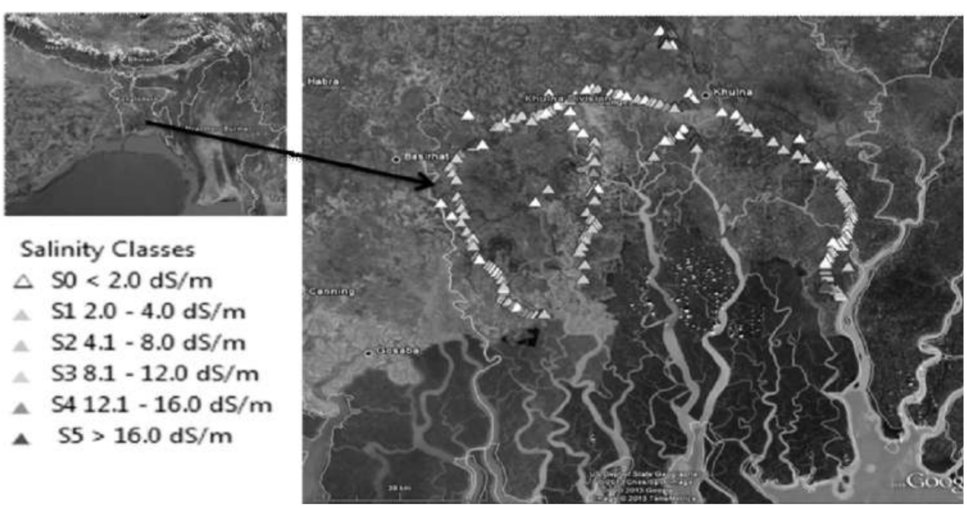

Figure 2.1. Study area (southwest coastal region) of Bangladesh
(Source: Prepared by the author based on GPS and EC (dS/m) data)

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 2 for more details).

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. his region has excessive shrimp culture.
2. his region possesses strong intensity of water and soil salinity.
3. his region is adjacent to the Bay of Bengal with high population density and highly degraded soil by salinity.
4. idal waves, storm surges and cyclones frequently hits and bring salinity from the Bay of Bengal.

2.2 Pling, Field survey, and data collection

To represents the population as a whole, compreheusive 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

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

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 indicates stochastic disturbance or error term with mean zero and variance . Factor shares for urea, TSP, phosphorus, green manures, and labor of crops production of equation (4) is given as

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

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

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

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

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

The major restrictions imposed on equations (4) is Symmetric restriction and restriction for Cobb-Douglas production function:

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

Linear homogeneity in factors of production:

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

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

Table 3.1: Regression coefficient estimates of per acre 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***	0.540871**
ln U	β_U	-1.087231*	-0.901031**	-1.326223**	-0.512390***	.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	-0.923209***	-0.667891***	-0.729321***	-0.233034***	-0.176540**
Pseudo 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 variables are significant except a few variables of all crops at the 1%, 5%, and 10% levels and show the expected sign.

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. The coefficients of the Aus rice model ranges from -1.087231 to 0.937983 (except intercept/constant value). Similarly, the coefficients of the Aman rice model, Boro rice model, Wheat model, and Cotton model ranges from (-0.901031 to 0.743292), (-1.326223 to 0.560369), (-1.174502 to 0.768972) and (-0.348509 to 0.912390) respectively. The Pseudo R^2 value indicates that 47% of the variation of the salinity is explained by the associate variables for the Aus rice model. On the other hand, The Pseudo R^2 values for the Aman rice, Boro rice, Wheat, and Cotton indicates that 39%, 56%, 57% and 52% of the variations of the salinity are explained by the associate variables. A one percent increase in salinity induced to reduce per acre Aus rice, Aman rice, Boro rice, wheat, and cotton production by 0.923209 kg, 0.667891kg, 0.729321kg, 0.233034 kg, and 0.176540 kg respectively. Low constant values of Aus rice and Boro rice models suggest that Aus rice and Aman rice are vulnerable to salinity.

4. Comparison among different crops with respect to average yield, income, total cost, profit, sowing and harvesting time.

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.

As a limited resource, Farmers of the Southwest coastal region have no scope to keep their land fallow. Furthermore, there is the possibility of occurrence of high intensity of salinity when the land remains uncultivated. To reduce the level of salinity and earn more profits, farmers of the southwest coastal region should

Table 4.1: Per acre average 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.)/acre	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)

cultivate high salinity tolerance crops like Cotton and Wheat. Per acre production cost of Cotton is bit higher than all varieties rice and wheat but farmers can get more profit to cultivate Cotton. On the other hands, per acre cost of Wheat is lower than the all varieties of rice and Cotton but farmers can also get more profits to cultivate Wheat. As more vulnerability to salinity and gets less profits from per acre Aus rice and Boro rice production, Farmers can sow Cotton and Wheat in the Aus rice and Boro rice season.

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 to for improve the crops productivity under salinity intrusion condition. 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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