Farmers' perception on climate change-driven rice production loss in drought-prone and groundwater-depleted areas of Bangladesh: An ordered probit analysis

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Abstract

The existing literature pays inadequate attention to any rigorous analysis of perceived severity of climate-driven crop losses, their determinants and implications. The present study fills this gap in three ways. It investigates farmers' perception about the severity of loss for three rice crops, identifies their determinants and explores policy implications. In doing so, it employs an ordered probit model to data from 1,800 farm households from districts typifying drought-prone and groundwater depleted areas of Bangladesh.

Perceived severity of rice production losses was not uniform for all rice crops being higher for the rain-fed crops and appeared broadly consistent with available evidence. Severity of perceived crop loss was associated with geophysical factors, household characteristics, institutional and market accessibility, and household adaptation strategy. Household resource endowment had no perceptible effect on production loss. The impact of these factors was specific to the crop and severity of perceived loss.

This study has several policy implications involving market, R & D and institutional support based options. Strengthening support systems for institutional and market accessibility, and science driven adaptation strategy including generation and wider dissemination of drought tolerant rice varieties, and enhancing farmers' capacity to change rice varieties on a regular basis constitute focal areas.

Keywords: Loss severity; Ground water depletion; Drought severity; Ordered probit; Accessibility; Adaptation strategy.

JEL Classification: O13, Q54, C35

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1. INTRODUCTION AND BACKGROUND

Bangladesh launched her Seventh Five-Year Plan (2016 - 2020)[1]in 2015 that envisioned GDP growth acceleration with environmental sustainability (GoB, 2015a). However, hurdles that Bangladesh confronted in the preceding decade or so include disaster preparedness and management, and adaptation measures fighting climate extreme events including droughts, floods, cyclones, sea level rise, salinity and soil erosion that hit Bangladesh with increasing severity and frequency (Majumder, 2013; Sarker et al., 2013b).

Rice, the dominant crop in Bangladesh, accounts for more than 90% of total cereal production covering 75% of Bangladesh's total cropped area (BBS, 2016; GoB, 2016). In the production year 2014-15, *boro* (winter-early summer, also known as *rabi*) rice accounted for 55%, while *aus* (summer-early monsoon, also known as *kharif 1*) rice and *aman* (monsoon-late autumn, also known as *kharif 2*) rice respectively contributed 7% and 38% of total rice production (BBS, 2016). *Aman* (mainly transplanted *aman* or T. *aman*) is a rain-fed monsoon rice crop while *boro* rice is a completely irrigated crop with an extremely high dependence on groundwater (Alauddin and Sharma, 2013). *Aus*, is both directly seeded and transplanted under rain-fed or limited irrigated conditions and grown in the very hot summer season (Rahman et al., 2009).

Insufficient rainfall leads to greater drought frequency and intensity, while increased evaporation increases the chance of complete crop failure (Liu et al., 2010; Reid et al., 2007). Of all climate change extremes, drought is not only the most widespread but also most damaging of all environmental stresses such as salinity, submergence, pests and diseases. According to an IRRI (International Rice Research Institute) estimate, droughts affect 23 million hectares of rain-fed rice in South and Southeast Asia and in some Indian states, droughts can cause 40% yield loss. (IRRI, 2016).

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[1]Financial year beginning July 2016.

Moreover, droughts can occur at any point or for any length of time during crop production and affect a wide range of physiological, biochemical and molecular processes. These complexities and the attendant uncertainty in timing of drought occurrence, intensity and duration pose formidable challenges for the scientific community. Increased temperature, variable rainfall, stronger storms, heat and cold waves, shifting of seasons, and groundwater depletion are regular phenomena arresting expected agricultural yields, undermining food security and ensuing health complexities and casualties (Rahman and Lateh, 2016a; Dey et al., 2012; Hijioka, 2014).Nelson et al. (2009) predicted production losses of 14%, 44-45% and 9-19% respectively for rice, wheat and maize relative to the no-climate-change scenario in the South Asian context.

Of the 13 severe droughts that hit Bangladesh in four decades to 2010, the ones occurring since the 1990s may be linked to climate change. Furthermore, recent years have witnessed increased frequency and severity of droughts (Rahman and Lateh, 2016b). Earlier studies reported that droughts affected nearly 50% of the land area (Ahmed, 2006; Shahid and Behrawan, 2008). It is projected that by 2050, the Barind Tract[2] will be at greater risk of droughts, as a result of a potential temperature increase of 2°C and a 10% decrease in rainfall. Temperature increase and rainfall reduction with increased variability further induce groundwater depletion with ramifications for irrigation water availability for crop production.

Climate change generally entails changes in two major climate variables: temperature and rainfall. The increase in temperature shortens the phenological phases of crops including planting, flowering and harvesting (Liu et al., 2010; Roudier et al., 2011; Teixeira et al., 2011) and affects plant growth and development. The photosynthesis rate of rice is at a maximum in the 20–32°C temperature range. Even a moderate increase of 1–2°C is likely to have an adverse

[2]A northwest upland region with hard red clay soil encompassing an area of 7,770 km^2.

impact on cereal yields (Schellnhuber et al., 2013). Fluctuations and occurrence of extreme climate events reduce rice yields significantly, particularly at critical crop growth stages (Alauddin and Hossain, 2001; Lansigan et al., 2000; Teixeira et al., 2011). Bangladesh ~~has~~ experienced rising temperature, particularly during monsoon, over the past three decades (UNDP, 2009; Rahman and Lateh, 2016b) and is likely to experience an increase in overall average temperature up to 1°C by 2030 and 1.4°C by 2050 (FAO, 2006; IPCC, 2014).

Rainfall in Bangladesh has recently become highly variable and has demonstrated an increasingly uneven distribution although the total annual rainfall remains almost the same. This erratic behaviour of rainfall produces noticeable adverse impacts on rice yields. Moreover, the variability and seasonality of monsoon rainfall further affect groundwater recharge during the wet season and may lead to increased exploitation during dry season (Schellnhuber et al., 2013; Alauddin and Quiggin, 2008). Alauddin and Sharma (2013) reported a two-way causation between mean groundwater depth and percentage of total area irrigated from groundwater sources in 10 of the 21 (greater) districts with about half of Bangladesh's cropped area.

In light of the above scenario, adaptation measures are important in combating these adverse sequels of climate change to ensure food security (Bradshaw et al., 2004; Reid et al., 2007).A number of studies focused on the determinants of farmers’ adaptation strategies and adaptive decisions to cope with climate change impacts (Alauddin and Sarker, 2014; Bahinipati and Venkatachalam, 2015; Wang et al., 2015). As a prelude to the assessment of adaptation strategies, it is critically important to investigate how farmers perceive production losses and choose to adopt appropriate measures and assess their effectiveness given that rain-fed crops are most vulnerable to climate change and are most likely to face higher potential production losses.

Against the above background, this study investigates the determinants of farmers' perception about production loss of three rice crops (*aman*, *aus* and *boro*) in drought-prone and groundwater depleted areas of Bangladesh. This is the first study of its kind for Bangladesh.

The remainder of the paper is organized as follows. Section 2 provides a review of the relevant literature on the developing world including Bangladesh. Section 3 explains materials and method while Section 4 presents and discusses empirical results. Section 5 provides conclusions and policy implications.

2. REVIEW OF LITERATURE

A number of studies paid attention to the economic impact of climate change on agricultural production in the context of developing countries (Chang, 2002; Deressa and Hassan, 2009; Gbetibouo and Hassan, 2005; Haim et al., 2008; Kabubo-Mariara and Karanja, 2007; Kurukulasuriya and Ajwad, 2007; Lansigan et al., 2000; Molua, 2009; Sanghi and Mendelsohn, 2008; Wang et al., 2009). However, studies on the impact of climate change on Bangladesh agriculture have focused either on assessing the impact of climate variables on rice productivity or farmers' adaptation strategies to reduce crop damage.

UNDP (2007) and, UNDP and GoB (2009) reported an *aman* rice crop production loss of 20-30% from the 2006 drought in the northwestern region of Bangladesh. BBS (2015) reported a 48% loss in the agriculture sector including crops, livestock and fishery and a crop loss of 36.2% due to climate change during the 2009-2014 period. Mottaleb et al. (2015) estimated an income decline of 9% of the shares of *aman* and *aus* rice crops in total income in the decade since 2000.

Rimi et al. (2009) analysed trends in climate variables for the 1950–2006 period and observed that the yields of *aus*, *aman* and *boro* rice crops were adversely affected by the rise in temperature, unpredictable rainfall, flooding, drought and salinity. Basak et al. (2010) assessed the impacts on the yields of BR3 and BR14 varieties of *boro* rice in 12 districts. Their model predicted an average yield reduction of over 20% and 50% for the two rice varieties for the years 2050 and 2070 respectively. Yu et al. (2010) estimated an average of 7.4% reduction in long-term rice production every year during the simulation period of 2005–2050. This result showed a reduction in *aman* and *aus* rice production in all sub-regions. Paul (1998) reported that the drought occurrence of 1994–95 adversely affected 15 distinct crops. The two most important crops were *aman* and *aus* rice respectively on average by 75% and 65%. Note that these two rice crops in 1994-95 accounted for 64% of the total rice crop in the study districts of greater Rangpur and Dinajpur (BBS, 2008).

Ahmed and Chowdhury (2006) examined local people's perceptions about past and present climate change and its consequences on rural livelihoods in two drought-prone districts, CHAPAI NAWABGANJ and NAOGAON in northwest Bangladesh. However, this study did not fcous on the extent of crop damage as a result of droughts. FAO (2006) reported that *aman* rice was the crop most affected by drought, with recorded production losses of up to 70%.

Sarker et al. (2012) reported significant impact of climate variables on rice in three crop seasons for the period of 1972-2009. However, this study did not gather empirical evidence on rice crops based on farm-level household survey data. Farmers' responses to climate change and adaptation strategies are likely to depend on a range of factors including socio-demographic and farm characteristics as well as institutional support.

Sarker et al. (2013a) investigated production variability of rice due to climate change while Alauddin and Sarker (2014) explored the determinants of farm-level adaptation strategies in ~~the~~ Bangladesh context. Farmers' responses towards the appropriate selection of these adaptation measures are driven by the extent of their perception about climate change and their access to extension services (Alauddin and Sarker, 2014; Bahinipati and Venkatachalam, 2015; Wang et al., 2015). These studies identified a number of barriers to adaptation including inadequate information, poor resource endowments and limited extension services (Alauddin and Sarker, 2014; Bryan et al., 2009; Deressa and Hassan, 2009; Deressa et al., 2009; Yesuf et al., 2008). Nevertheless, the micro-level studies in existing literature are far outnumbered by the voluminous literature on aggregate macro-level analysis. A body of literature with a rigorous investigation of the determinants of farmers' perception about severity of production loss due to climate change is yet to emerge.

This study fills this gap and contributes in three ways. First, it investigates farmers' perception about the severity of loss for three rice crops. Second, it identifies the determinants of the perceived crop loss. Finally, it explores policy implications.

3. MATERIALS AND METHODS

3.1 Study Area, Survey and Data

This study was carried out in nine sub-districts of eight districts, CHAPAI NAWABGANJ, NAOGAON, NATORE, RAJSHAHI, PABNA, CHUADANGA, BOGRA, and GAZIPUR. Figure 1 depicts the map of Bangladesh with the arrows showing the approximate locations of the study areas. Among these, the five sub-districts from four districts (Nachol #1 from CHAPAI NAWABGANJ, Porsha #2 from NAOGAON, Tanor #3 and Charghat #4 from RAJSHAHI, and Lalpur #5 from NATORE)located in the western climatic zone consisted of 771 valid observations. Very severe drought, high temperature and severe groundwater scarcity characterize these five locations. Three sub-districts, Ishurdi #6 from PABNA, Damurhuda #7 from CHUADANGA, and Sariakandi #8 from BOGRA (N= 689) from the north western climatic zone represent moderate level of drought severity and groundwater abstraction. One sub-district Kapasia #9 from GAZIPUR in the south central climatic zone (N = 340) has experienced the most severe decline in groundwater table (Alauddin and Sharma, 2013). Thus, farm-level data from 1,800 households from nine sub-districts of eight districts typifying drought-prone and groundwater-depleted areas of Bangladesh form the empirical basis of the present study.

A structured survey questionnaire with a face-face interview method was employed to elicit data from the head of each farm household. Sample size for each of the sub-districts was proportional to the farming households of the particular location. Sampled households were randomly selected for interviewing from a sampling frame with the use of computer generated random numbers. A pilot survey preceded the administration of the survey.

Information on farmers' perception and knowledge about the severity of production loss for three rice crops (*aus*, *aman*, *boro*) were collected. Farmers' perceptions are important as they first perceive the severity of losses and then, based on these perceptions, they formulate decisions about adaptation strategies to diminish losses. The survey also included information (Table 1) on household characteristics (including age of the household head, farming experience and family size), household resource endowments (including ownership of land, and livestock), institutional and market accessibility (e.g., access to credit, subsidy, climate information, and distance to local market), household climate change adaption strategy (including supplementary irrigation, greater frequency of irrigation, crop switching, mango orchard instead of rice, cultivation of drought tolerant and short-maturing rice varieties). The contribution of these factors could potentially have important policy implications to reduce climate-driven crop losses.

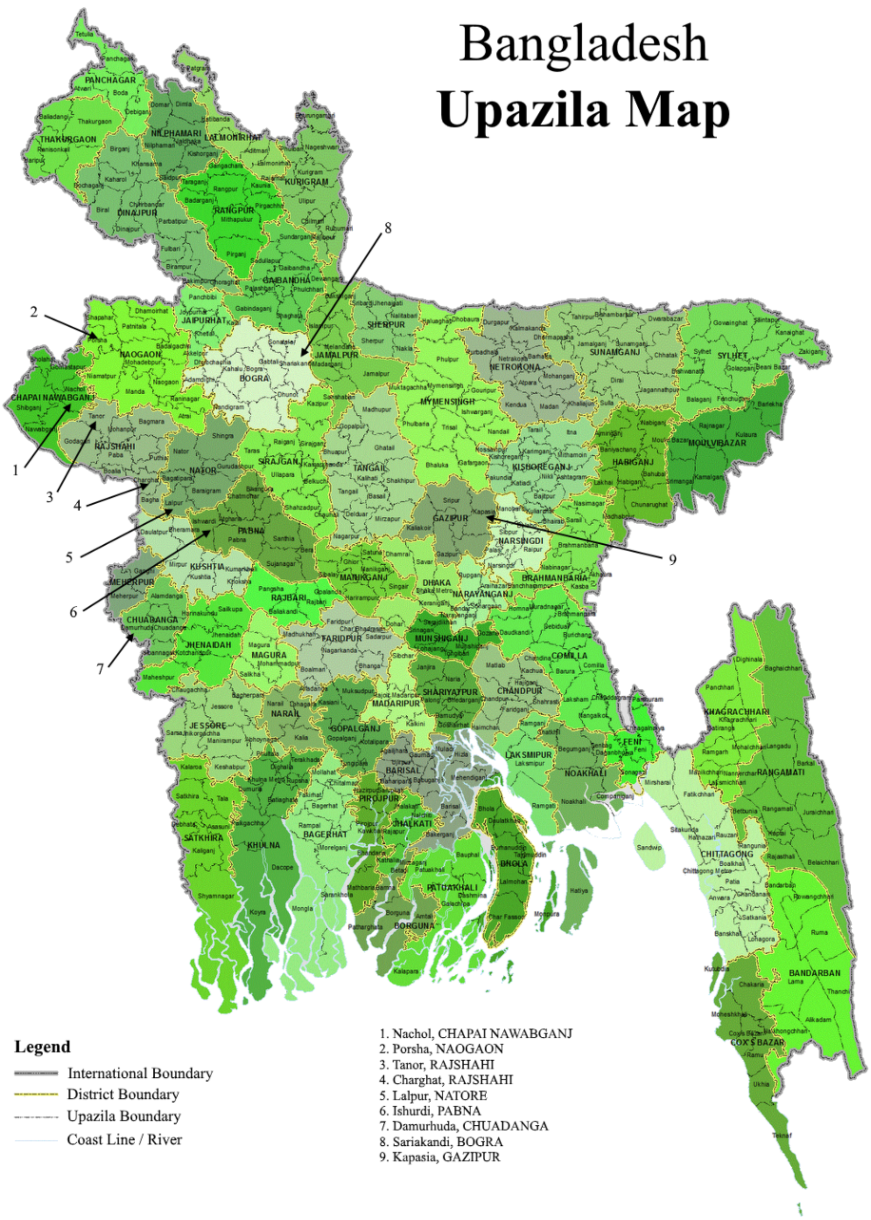

Figure 1: Map of Bangladesh showing study areas (Source: Adapted from http://maps-of-bangladesh.blogshot.com/).

Table 1: Description of probable independent variables

Variable type and description
Geo-physical status of survey area
Drought: 1 (very severe): Nachol #1, Porsha #2, Tanor #3, Charghat #4, Lalpur #5; 0 (Otherwise): Ishurdi #6, Damurhuda #7, Sariakandi #8, Kapasia #9.
Groundwater depletion: 1 (very severe): Nachol #1, Porsha #2, Tanor #3, Charghat #4, Lalpur #5; Kapasia #9; 0 (Otherwise): Ishurdi #6, Damurhuda #7, Sariakandi #8.
Household characteristics
Household head age: in years
Household head gender: 1= Male, 0= Female
Household head education: Schooling in years
Household size: Household size in number
Farming experience: Years
Household resource endowment
Income: Annual household income (‘000 BDT)
Ownership of arable land: in decimal (1 decimal = 40.46 m^2)
Livestock ownership: 1= Yes, 0= No
Institutional and market accessibility
Access to climate information: 1= Yes, 0= No
Access to subsidies: 1= Yes, 0= No
Home to local market distance: Kilometres
Institution/group membership: 1= Yes, 0= No
Accessibility to credit: 1= Yes, 0= No
Household adaptation strategy
Use of direct seeded rice: 1= Yes, 0= No
Greater usage of irrigation for *boro* rice: 1= Yes, 0= No
Supplementary irrigation for *aman rice*: 1= Yes, 0= No
Supplementary irrigation for *aus* rice: 1= Yes, 0= No
Cultivation of short duration *aus* rice varieties: 1= Yes, 0= No
Cultivation of short duration *aman* rice varieties: 1= Yes, 0= No
Cultivation of short duration *boro* rice varieties: 1= Yes, 0= No
Changing rice planting/harvesting dates: 1= Yes, 0= No
Tree plantation replacing rice: 1= Yes, 0= No
Cultivation of drought tolerant rice varieties: 1= Yes, 0= No
Changing rice varieties every year: 1= Yes, 0= No
Cultivation of non-rice *rabi* crops e.g., potatoes, pulses, oilseeds: 1= Yes, 0= No
Using water-saving technology e.g., alternative wet and dry (AWD): 1= Yes, 0= No

3.2 Model Selection and Specification

The target variable for this study, rice farmers’ perception about the severity of climate-driven production loss, is ordinal. The severity of damage is classed into three ordinal categories as Low (0-20% loss), Moderate (21%-35% loss), and High (36%-70% loss). For analyzing such ordinal data, the literature employs ordered logit and probit models.[3] However, the selection between the two models is chiefly a matter of convenience and which model is most commonly used in the relevant area of research (Long, 1997). This study employs the ordered probit model as it has wider applicability to assess the ordinal nature of a target variable. Following Greene (2012) and Long (1997), Equation 1 specifies the model.

$$y_i^* = x_i\beta + \varepsilon_i \tag{1}$$

Where y_i^*= loss severity with three levels in increasing severity, coded as 1= low, 2= moderate, and 3 = high; x_i= vector of observed non-random explanatory variables assessing the attributes of loss severity; and ε_i= a random error term with mean 0 and variance 1. The observed y is related to y^*as specified in Equation 2.

$$y_i \begin{cases} 1 \Rightarrow \text{low loss} \quad \text{if } \tau_0 = -\infty \leq y_i^* < \tau_1 \\ 2 \Rightarrow \text{Moderate loss if } \tau_1 \leq y_i^* < \tau_2 \\ 3 \Rightarrow \text{severe or high loss if } \ \tau_2 \leq y_i^* < \tau_3 = \infty \end{cases} \tag{2}$$

The τ's indicate the thresholds or cut-points to be projected for each level. Therefore, as explained in Long (1997), the formulas for the probabilities with three observed outcomes for the ordered probit model will be:

$$\begin{cases} P_r(y_i = 1/x_i) = \phi(\tau_1 - \alpha - \beta x_i \\ P_r(y_i = 2|x_i) = \phi(\tau_2 - \alpha - \beta x_i) - \phi(\tau_1 - \alpha - \beta x_i\ ) \\ P_r(y_i = 3|x_i) = \phi(\tau_3 - \alpha - \beta x_i) - \phi(\tau_2 - \alpha - \beta x_i\ ) \end{cases} \tag{3}$$

The parameters of the model specified in Equation 3 are estimated using the maximum likelihood method. However, there is a lack of clarity in interpreting the coefficients of the model. For example, there are three categories of the loss severity variable while the model has

[3]These two models are essentially same, the only difference being their distributions. The logit model follows cumulative standard logistic distribution function while standard normal distribution is followed in the probit model. However, both the models provide similar results (Long, 1997; Greene, 2012).

only one unknown threshold parameter (Greene, 2012). This necessitates for the partial change or marginal effect which can reveal the effects of independent variables on the probability of three different levels of production loss severity individually. A partial change in the predicted probability of the outcome m, for a continuous variable, in the interval τ_{m-1} to τ_m for a change in an explanatory variable x_k at the mean value is specified as Equation 4.

$$\frac{\delta P_r(y=m|\bar{x})}{\delta x_k} = \beta_k[f(\tau_{m-1} - \bar{x}\beta) - f(\tau_m - \bar{x}\beta)] \quad (4)$$

On the other hand, the change in the predicted probability for a discrete changes in x_k from the initial valuex_S to the end value x_E (e.g., a change from $x = 0$ to $x = 1$) is given by Equation 5:

$$\frac{\Delta P_r(y=m|x)}{\Delta x_k} = P_r(y = m|x, x_k = x_E) - P_r(y = m|x, x_k = x_S) \quad (5)$$

Where $P_r(y = m|x, x_k)$ states the probability that $y = m$ given x, stating a particular value for x_k. Thus, when x_k changes from x_S to x_E, the predicted probability of outcome, m changes by $\Delta P_r(y = m|x)/\Delta x_k$, holding all other variables at x.

4. RESULTS AND DISCUSSION

4.1 Interpretive Overview of the Severity of Perceived Rice Production Loss

Figure 2 illustrates the dependent variable i.e., perceived production loss. The incidence of the perceived production loss varied across the three crops of rice. The incidence of the perception of high production loss was the highest for *aus* rice to the 31.2% of households followed closely by the one for *aman* rice (27.2%) while it was the lowest for *boro* rice (14.1%). For *aman* rice, the perceived moderate crop loss was the highest (34.1%) followed by *aus* rice (25.4%) and *boro* rice (21.5%). The incidence of perceived low production loss was the highest for *boro* rice (64.4%) with the respective figures for *aus* and *aman* rice crops being 43.5% and 38.7%.

It appears that the greater the dependence on rainfall, the higher the perceived production loss at the upper end for *aus* and *aman* rice crops.

Once the moderate and high loss figures (21-70%) were combined, the incidence for *aman* rice crop loss was the highest (61.3%) followed closely by *aus* rice crop (56.5%) while it was 35.6% for *boro* rice. Given the overwhelming importance (≥90%) of *aman* and *boro* rice in total rice production, the incidence of perceived production loss in excess of 20% for both of them are quite substantial with significant ramifications for food availability which is a central plank of food security.

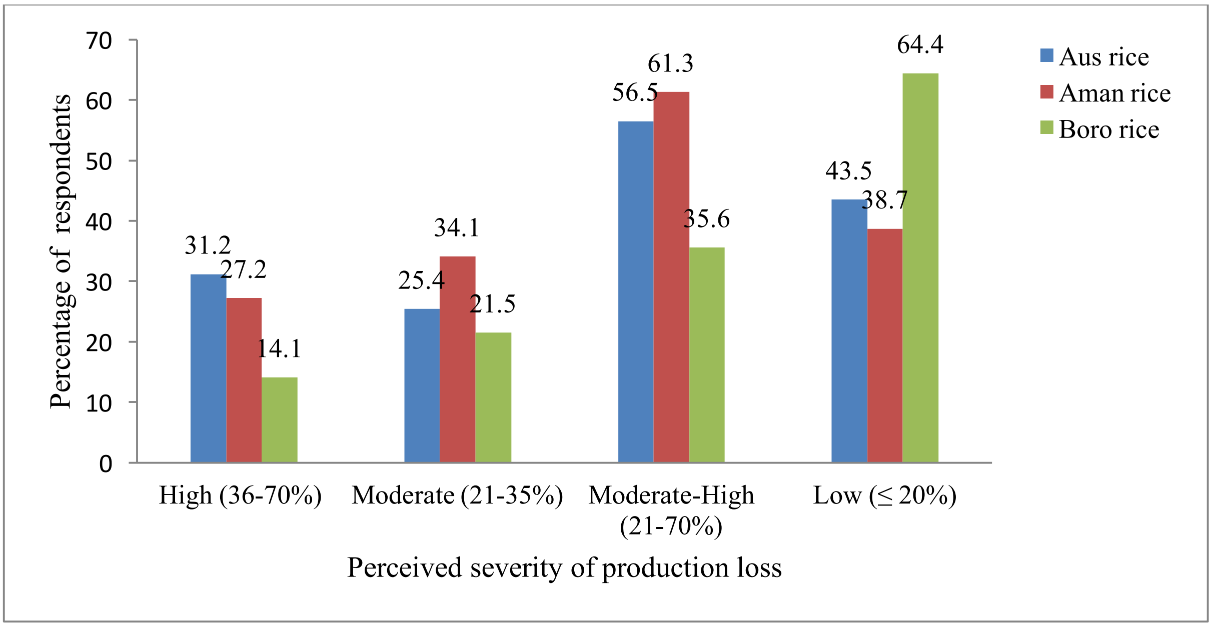

Figure 2: Farmers' perception of severity of rice production loss (%)

4.2 Results of Ordered Probit Analysis

This section evaluates the impacts of a set of explanatory variables typifying geo-physical status of survey area, household characteristics, household resource endowment, institutional and market accessibility, and household adaptation strategy (as stated in Table 1). The results are presented sequentially for each rice crop.

Aus rice crop

Table 2 sets out results for the *aus* rice crop model. Overall, the model appears to be satisfactory given it is statistically significant at $p< .01$ with pseudo R^2 of 0.10 and log likelihood of -314.60 A closer inspection of the information contained in Table 2 suggests that drought severity, groundwater depletion, age and gender, and farming experience of the household head, home to local market distance, replacing field crops with horticultural crops, and changing rice varieties every year appear as significant determinants of farmers' perception of crop losses. More specifically, perceived production loss varies directly with groundwater scarcity, and age, male gender as the parameters of these variables contain positive sign. On the other hand, drought severity, farming experience, distance to local market from home, switching to horticultural crops and changing rice verities every year appeared to be production-loss decreasing factors since their respective coefficients display negative signs. However, these coefficients cannot directly reveal the effects of the regressors on each of the three different levels of production losses. To overcome this problem, marginal effects indicated by $\delta y/\delta x$ were evaluated at the corresponding levels of production loss.

Results for the probability of low production loss were different from moderate and high severity cases as well as in case of individual variables' contribution. The probability of low production loss decreased with groundwater scarcity, age and male household heads. It increased with drought severity, farmers' experience, and distance to local market from home. Drought diminished high level of perceived production loss by 38.5% while it increased the low level by 37.4%. Groundwater scarcity reduces low level of perceived production loss by 57.2%. However, it increases moderate and high levels of perceived losses by 19.7% and 37.4% respectively.

Thus, the results for drought severity and groundwater scarcity were very similar. Drought severity and groundwater scarcity induce farmers to switch to some adaptation strategies including direct seeding, changing planting dates, drought-tolerant variety cultivation (Alauddin and Sarker, 2014). This could happen due to increased groundwater abstraction and reduced possibility of water recharge followed by a reduction in area under cultivation (Keshavarz and Karami, 2016).

Table 2: Model results for *aus* rice crop

Variables	Parameter	Marginal effect ($\delta y/\delta x$)		
		Low (≤ 20%)	Moderate (21-35%)	High (36-70%)
Drought	-1.066***	0.374***	0.0106	-0.385***
Ground water depletion	1.658***	-0.572***	0.197***	0.374***
Age	0.0294**	-0.0115**	0.00157*	0.00993**
Gender	1.260*	-0.436***	0.184*	0.252***
Education	-0.0193	0.00754	-0.00103	-0.00651
Household size	-0.0123	0.00480	-0.000654	-0.00415
Farming experience	-0.0349***	0.0137***	-0.00186**	-0.0118***
Household income	3.98e-09	-1.56e-09	2.12e-10	1.35e-09
Ownership of arable land	-0.000100	0.0000393	-0.0000054	-0.0000339
Livestock ownership	0.0662	-0.0260	0.00400	0.0220
Access to climate information	-0.124	0.0484	-0.00698	-0.0414
Access to subsidies	-0.0341	0.0134	-0.00187	-0.0115
Access to credit	-0.145	0.0567	-0.00723	-0.0495
Home to local market distance	-0.0687**	0.0269**	-0.00367*	-0.0232**
Institution/group membership	0.238	-0.0914	0.00821	0.0832
Direct seeded rice	0.0507	-0.0198	0.00240	0.0174
Supplementary irrigation for *aus*	0.191	-0.0736	0.00715	0.0664
Changing rice planting/harvesting date	-0.289	0.114	-0.0216	-0.0925
Tree plantation, in place of crop, mainly, mango orchard	-0.437**	0.173**	-0.0380	-0.135***
Cultivation of drought tolerant rice varieties (e.g., *BRRIdhan-56*, *BRRIdhan-57*, *Swarna*)	-0.156	0.0616	-0.0102	-0.0515
Changing rice varieties every year	-0.349*	0.138*	-0.0268	-0.111**
N	327			
Log likelihood	-314.60			
Pseudo R^2	0.10			
p-value	0.000			

***p<.01, **p<.05, *p<.10

Aman rice crop

Table 3 reports results of the estimated model for *aman* rice crop. On the whole, the model seems satisfactory given it is significant at p<.01 with a pseudo R^2 of 0.03 and log likelihood of -1631.27. Looking at the individual coefficients in Table 3, eight independent variables (groundwater depletion, access to climate information, access to subsidies, access to credit, membership of an institutional group, changing planting/harvesting date of rice cultivation of drought tolerant rice varieties, changing crops with tree plantation and changing rice varieties every year) were found to be statistically significant. Severity of groundwater depletion, access to climate information, access to subsidies, and membership of an institution/group positively influenced perceived crop production losses. On the other hand, access to credit, changing planting/harvesting date of rice, cultivation of drought tolerant rice varieties, and replacing crops with tree plantation influenced them negatively.

While evaluating the marginal effects, statistically significant variables were similarly found for the probabilities of low, moderate and high production losses apart from a few exceptions. Specifically, the probability of low production loss case was different from the moderate and high losses. Groundwater depletion, access to climate information, access to subsidies and membership of an institution or a group, diminish low severity whereas they are loss increasing factors for moderate and high severity case. Groundwater scarcity decreases low severity by 18.8% and increases moderate severity by 3.51% and high severity by 15.3%.

It appeared that farmers perceiving moderate and high production loss lacked adequate access to climate information. Earlier studies (Sarker et al., 2013b; Alauddin and Sarker, 2014) also identified this as a barrier to adaptation. Access to climate information is decisive in adopting climate-smart strategies to contain climate-driven losses (Alam, 2015; Deressa and Hassan, 2009; Nhemachena and Hassan, 2007). Institutional or group membership reduces probability of perceived low production loss by 10.1% but increased it for moderate and high production losses respectively by 1.43% and 8.68%. This contrasts with the findings of Alam (2015). Access to subsidies reduced low production loss by 4.81% and had a minimal effect on medium production loss but increased high production losses by 4.13%.

Table 3: Model results for *aman* rice crop

Variables	Parameter	Marginal effect (*δy/δx*)		
		Low (≤ 20%)	Moderate (21-35%)	High (36-70%)
Drought	-0.139	0.0530	-0.00787	-0.0451
Ground water depletion	0.490***	-0.188***	0.0351***	0.153***
Age	-0.00221	0.000842	-0.000119	-0.000723
Gender	-0.249	0.0905	-0.00359	-0.0869
Education	0.00607	-0.00232	0.000327	0.00199
Household size	0.00626	-0.00239	0.000337	0.00205
Farming experience	0.00220	-0.000839	0.000119	0.000720
Income	1.47e-08	-5.60e-09	7.91e-10	4.81e-09
Ownership of arable land	-.0000226	.00000863	-00000122	-.00000741
Livestock ownership	-0.107	0.0400	-0.00418	-0.0358
Access to climate information	0.113*	-0.0429*	0.00586*	0.0371*
Access to subsidies	0.127**	-0.0481**	0.00643**	0.0417**
Access to credit	-0.154**	0.0587***	-0.00826**	-0.0504**
Home to local market distance	0.0158	-0.00602	0.000850	0.00517
Institution/group membership	0.265***	-0.101***	0.0143***	0.0868***
Direct seeded rice	-0.0493	0.0189	-0.00298	-0.0159
Supplementary irrigation for *aman rice*	0.0108	-0.00413	0.000580	0.00355
Changing rice planting/harvesting date	-0.297***	0.115***	-0.0244**	-0.0910***
Tree plantation, in place of crop, mainly, mango orchard	-0.179**	0.0693**	-0.0129*	-0.0564**
Cultivation of drought tolerant rice varieties (e.g., *BRRIdhan*-56, *BRRIdhan*-57, *Swarna*)	-0.158**	0.0609**	-0.0107*	-0.0503**
Changing rice varieties every year	0.0582	-0.0221	0.00279	0.0193
N	1,546			
Log likelihood	-1631.27			
Pseudo R^2	0.030			
p-value	0.000			

****p*< .01; ***p*< .05; **p*< .10.

Access to credit, changing planting/harvesting date of rice, replacing crops with tree plantation, and cultivation of drought resistant varieties of rice while increasing the probability of perception of low production losses reduces it for perceived moderate and high production losses. For example, changing planting/harvesting date of rice leads to an 11.5% increase in probability of low production loss while it reduces the same respectively by 2.44% and 9.1% for the moderate and high production loss cases.

Boro rice crop

Table 4 sets out the results for *boro* rice crop. Overall, the model has the utility having Pseudo R^2 of .063 and log likelihood of -1231.49 at $p< .01$. The regressors for the *boro* rice model are jointly and statistically significant in determining perceived levels of production loss. Eight variables (drought, groundwater depletion, gender, household size, livestock ownership, access to climate information, access to subsidies and distance to market) significantly affect farmers' perception of production losses. Among these, groundwater depletion, male household head, household size, and household size were loss increasing factors. On the other hand, drought severity, livestock ownership, home to local market distance, cultivation of drought-tolerant varieties, and changing rice varieties every year diminish loss severity.

While computing marginal effects, with the exception of livestock ownership for high severity, the effect of other seven variables on farmers' perception about moderate and high production losses were similar to the case of the corresponding directions their contributions set out in Column 2 of Table 4. Results for the low severity of perceived production loss differed from those for moderate and high severity cases for all statistically significant variables.

Drought severity increased low production loss probability by 15.4% but reduced moderate and high loss probabilities by 7.37% and 8% respectively. This finding though somewhat surprising, may not be at odds with the conventional wisdom that with greater drought severity, farmers are more likely to adapt to strategies fighting drought. This seems compatible with some earlier studies on adaptation decisions and strategies (Alauddin and Sarker, 2014; Keshavarz and Karami, 2014, 2016; Venot et al., 2010). Though groundwater scarcity has a decreasing influence on the low scale of production loss, increased abstraction of groundwater to be used for irrigation supporting some adaptation strategies would lead to further lowering of groundwater table. Moreover, lesser possibility of recharge due to inadequate monsoon rain in drought-prone areas worsens the scenario (Adham et al., 2010) exacerbating the severity of production loss.

Livestock ownership increased probability of low production loss by 7.29% but reduced it by 3.12% for the moderate loss case. Groundwater depletion decreased probability of low loss severity by 18.7% but it increased those of moderate and high severity respectively by 8.86% and 9.8%.

Access to climate information reduced low severity loss by almost 10% but increased the probability of moderate and high severity cases respectively by 4.53% and 5.41%. Two important adaptation strategy related factors e.g., cultivation of drought-tolerant rice varieties and changing rice varieties every year while increasing the probability of low production loss respectively by 18.6% and 9.96% reduced probabilities of moderate production loss by 9.61% and 4.95% and that of high production loss by 9.02% and 5.02%.

Table 4: Model results for *boro* rice crop

Variables	Parameter	Marginal effect ($\delta y/\delta x$)		
		Low (≤ 20%)	Moderate (21-35%)	High (36-70%)
Drought	-0.436***	0.154***	-0.0737***	-0.0800***
Ground water depletion	0.530***	-0.187***	0.0886***	0.0980***
Age	-0.000839	0.000305	-0.000141	-0.000164
Gender	0.653**	-0.196***	0.111**	0.0855***
Education	0.00943	-0.00343	0.00159	0.00185
Ownership of arable land	-0.000266	.0000969	-.0000448	-.0000521
Household size	0.0391***	-0.0142***	0.00658***	0.00765***
Farming experience	-0.00138	0.000502	-0.000232	-0.000270
Income	-5.77e-08	2.10e-08	-9.70e-09	-1.13e-08
Ownership of arable land	-0.000266	.0000969	-.0000448	-.0000521
Livestock ownership	-0.195*	0.0729*	-0.0312*	-0.0417
Access to climate information	0.273***	-0.0994***	0.0453***	0.0541***
Access to subsidies	-0.0743	0.0270	-0.0125	-0.0145
Access to credit	-0.0302	0.0110	-0.00507	-0.00590
Home to local market distance	-0.0306**	0.0111**	-0.00515**	-0.00598**
Institution/group membership	0.0988	-0.0359	0.0166	0.0193
More irrigation for *boro* rice	0.0714	-0.0259	0.0120	0.0139
Cultivation of short duration rice varieties (e.g., *BRRIdhan-45*, *BRRIdhan-28*, Bina 7)	-0.0862	0.0313	-0.0146	-0.0167
Tree plantation, in place of crop, mainly, mango orchard	0.0699	-0.0257	0.0116	0.0141
Cultivation of drought tolerant rice varieties (e.g., *BRRIdhan-56, BRRIdhan-57*)	-0.561***	0.186***	-0.0961***	-0.0902***
Changing rice varieties every year	-0.287***	0.0996***	-0.0495***	-0.0502***
Cultivation of non-rice *rabi* crops (e.g., potato, pulses, oilseeds).	0.00824	-0.00300	0.00138	0.00161
Use of water saving technology (e.g., AWD)	0.143	-0.0534	0.0231	0.0303
N	1,475			
Log likelihood	-1231.49			
Pseudo R^2	0.063			
p-value	0.000			

***$p < .01$; **$p < .05$; *$p < .10$.

5. CONCLUSIONS AND POLICY IMPLICATIONS

This study examined farmers' perception about severity of loss induced by climate change for three rice crops *aus*, *aman* and *boro*. The first two rice crops are primarily rain-dependent while the third one is almost completely groundwater irrigation dependent. The study categorized the perceived production losses into three categories: low (≤20%), medium (21-35%) and high (36-70%). The study identified likely determinants of perceived production loss generally.

Furthermore, the marginal impacts of these factors suggested that they varied across the three crops and the three different levels of the severity of production loss.

5.1 Summary of Conclusions

The incidence of the perception of high production loss was appreciably greater for *aus* and *aman* crops than for *boro* crop. The incidence of perceived low production loss was the highest for *boro* rice. The perceived production loss at the upper end for *aus* and *aman* rice crops were due to their overwhelming dependence on rainfall. These findings were consistent with those of earlier studies (Paul, 1998; UNDP, 2007, UNDP and GoB, 2009, BBS, 2015). The incidence of perceived loss figures exceeding 20% for *aman* and *boro* rice crops given their overwhelming importance in total rice production have significant ramifications for food grain availability.

Drought appeared to diminish perceived loss of *aus* and *boro* crops. Marginal effects suggested that drought was low loss enhancing but perceived high loss decreasing for both crops. In case of *boro* crop this factor had only a perceived medium loss reducing effect.

Groundwater scarcity appeared to increase perceived production loss of all three rice crops. While looking into different categories of production loss, severity of groundwater depletion is likely to aggravate moderate and high severity of loss for all rice crops, though it might reduce the likelihood of ameliorating perceived low loss.

Among the factors typifying household resource endowment only livestock ownership had a likelihood of low loss increasing but medium loss decreasing effect for *boro* rice crop.

Age had significant but a minimal impact on any category of perceived loss only for *aus* crop. However, male household head had a significant perceived medium and high loss enhancing but a low loss reducing effect for *aus* and *boro* crops. Household size had a significant but marginal positive effect on medium and high categories of perceived crop loss. Farming experience mattered in reducing *aus* rice crop loss only.

Factors underpinning access to institutional and market accessibility climate have differentially affected perceived crop loss. An important factor on the face of climate change and mitigating its consequences, farmers' access to climate information has been observed as a crucial issue needs to be taken care of. The study observed deficiency of farmers' access to climate information in all seasons' rice crops, because the variable individually increases production loss. Not only it contributed individually, but also access to climate information played an increasing role for the farmers' perceiving moderate and high severity.

Access to subsidies during *aman* season could reduce low loss severity, though it could increase probability of high and moderate severity *albeit* marginally. Access to credit could reduce the probability of medium and high losses for *aman* crop but could increase the one for a low loss case.

Distance of local market from home reduces *aus* and *boro* rice production loss, even though its contribution was quite negligible. Institutional/group membership was significant in determining *aman* rice production loss. The study found institutional/group membership individually, a critical barrier to mitigate production loss. However, only the farmers perceiving low severity could reduce their losses holding such memberships while it increased the likelihood of increasing higher losses for *aman* rice crop.

The four factors that underlie household strategy for adaptation to climate change affected perceived production loss significantly but differentially. Tree plantation (mainly mango orchard) replacing crops did have a low loss increasing but high loss reducing effect for *aus* and *aman* rice crops. Changing rice varieties every year had a low loss increasing but medium and high loss reducing effect for *aus* and *boro* rice crops. The likelihoods in all corresponding cases were higher for *aus* relative to *boro* crop. Changing planting and harvesting time was significant and substantial for high loss reducing for *aman* rice. However, it was significantly and substantially low loss increasing but had a significant but marginal medium loss reducing effect. Cultivation of drought-tolerant varieties of rice generally had a loss reducing effect for both *aman* and *boro* rice. It was low loss increasing for both crops but with a far stronger chance for *boro*. However, it reduced the likelihood of medium and high loss cases for both rice crops. The chance of such reductions for *boro* was much higher than that for *aman* rice crop.

5.2 Policy Implications

The findings of this study have several policy implications for creating an enabling environment for the farming community to minimise crop losses due to climate induced changes in production conditions.

These relate primarily to scientific breakthroughs, the provision of stronger institutional support services for farmers, easier access to relevant information, and wider access to community-based farming education to facilitate more effective agronomic and crop culture practices. Given the complex nature of drought as a phenomenon, development of drought-tolerant and short maturing varieties are of critical importance.

Given the intense pressure on groundwater a two-pronged strategy can be adopted: (a) a gradual but substantial shift from dry season rice to non-rice crops such as pulses and vegetables that are less water-consuming; and (b) a reduction in relative dependence on the *rabi* (*boro)*and an expansion of the scope of *kharif* (*aus* and *aman*) rice crops.

Strategy (a) above entail a partial reallocation of land from rice to non-rice crops and does not necessarily imply a reduction in rice output in the *rabi* (dry) season. The *rabi* rice output could be maintained at the present level or even increased by bridging the significant gap between potential and actual yields through better input and resource management (Mandol, 2011). The land released from dry season rice cropping could be allocated to other crops of higher nutritional value but less water consuming in nature. Afzal et al. (2004, p.60) reported that all major varieties of pulses provide about the same amount of energy as rice but nearly four times as much protein, 8-18 times as much calcium but no more than 80 per cent of carbohydrate.

Strategy (b) warrants a significant expansion of HYV rice technology in *kharif* season, especially *aman* (*kharif* 2) through: (i) stronger provision for supplementary irrigation to *kharif* HYV areas; and (ii) greater adaptability of *kharif* HYVs to various environmental conditions.

The two-pronged above strategy outlined above is underpinned, amongst others, by three categories of policy options: market-based, R & D-based and institutional support-based.

Market-based option

This option relies on setting input prices to close to their scarcity so that they reflect resource endowment. In Bangladesh, pricing of material inputs such as fertilizers, pesticides and irrigation equipment and other machinery has rationalized through policies that have evolved in the 1980s and 1990s. This included the removal of subsidies and exchange rate distortions, However, environmental goods such as groundwater, has been treated as a ‘free’ good even though it is a scarce resource in many parts of Bangladesh and is becoming more so with time. The owners of irrigation machinery such as deep tube wells abstract underground water for irrigating their own land and charge a fee at commercial rates for irrigating others’ land. Pricing per cubic meter of water irrigated or engine capacity a fee can be introduced just to demonstrate at least partially the true value of this environmental good. The former is difficult to enforce in practice but the latter is relatively easier to implement. One other instrument complementary to those mentioned above is to design incentive mechanisms for innovation of the environment-saving type e.g., water and energy saving mechanical innovations.

R & D-based option

The essential elements of this option include *inter alia* the following:

It is critically important to develop crop varieties that are less water-using (water-saving). These include rice as well as non-rice crops. Given the importance of rice, for Bangladesh it is a virtual rice monoculture and there is significant reliance on ground-water irrigation during dry season. This involves developing technologies/providing incentives for greater usage of surface water for irrigation given its relative abundance in some parts of Bangladesh. This assumes greater significance because rapid urbanization will put considerable strain on groundwater tables for the supply of water for domestic usage in urban areas.

Research at the International Rice Research Institute (IRRI, 2016) suggests a 0.8-1.2 tons per hectare yield advantage of drought-tolerant varieties under drought conditions over the drought susceptible ones. Current IRRI research also focuses on drought-tolerant characteristics into pre-existing HYVs of rice including IR64, *Swarna*[4], and *Vandna*. In Bangladesh, despite drought having been a focus of agricultural research for several decades, progress in delivering drought adapted rice varieties and technologies has been relatively slow. Among the Bangladesh Rice Research Institute (BRRI) varieties *BRRIdhan-56* (released in 2011) and *BRRIdhan-66* (released in 2014) are drought tolerant, while *BRRIdhan-57* (released in 2011) (BRRI, 2016a) is able to avoid terminal drought due to shorter growth duration. All of these new strains of rice are suitable for the *aman* season. It should also be noted that adoption rate of *BRRIdhan-56* and *BRRIdhan-57* is extremely low (0.17% and 0.12% respectively, BRRI, 2016b). The seeds of these varieties are yet to be readily available for widespread dissemination. BRRI research on development of further drought tolerant rice varieties has been continuing independently under national program as well as with collaboration from

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[4]Kabir, Alauddin and Crimp (2016) found that *Swarna* was widely adopted (grown in 85% of the wet season rice area in a case study village in Western Bangladesh, as it was more drought and pest tolerant than other available rice varieties.

IRRI.[5]However, a significant increase in investment in agricultural research and development from its current low level is required in order for Bangladesh to adapt and cope with the adverse effects of drought severity.

Of paramount importance is to extend and intensify research efforts toward developing HYVs of non-rice crops e.g. pulses and vegetables which are financially attractive to farmers and can partially but effectively replace *rabi* rice cropping. These crop varieties must contain multiple attributes involving wider adaptability to temperature variations, higher yields and lower consumptive water usage.

Institutional support

Assisting farmers to put in place successful strategies to offset the adverse effects of climate change warrants significantly stronger support services such as easier access for farmers to relevant information and improved extension services. Reliable forecasting of adverse climatic events such as droughts can also enhance farmers' preparedness for adaptation to climate change. In this respect accessibility to internet could be an important avenue. Note that in order to ensure the rapid spread of information and communication technology (ICT) Bangladesh government launched the 'Info Sarkar' project aiming to create an ICT network to link up more than 17,000 government offices ranging from *upazilas* (sub-districts) to union councils (second lowest and lowest tiers of government). The government set up more than 4,500 Union Information Service Centres (UISC, later renamed as Union Digital Centre, UDC) with internet facilities to provide easier accessibility to internet services at the grassroots' level (Khan, 2016). Ullah (2016) found that the educated young were accessing the ICT facilities at the UDCs to good use in a wide range of areas. The challenge is to use the ICT-literate young

[5]Personal communication with Dr M. Jahangir Kabir, Agricultural Economics Division, Bangladesh Rice Research Institute, Joydebpur, Gazipur 1701.

people as change agents to disseminate knowledge to the farming community to manage drought and other climate related adversities.

Input supply and delivery system involving adequate and timely availability of critical inputs such as fertilizers and irrigation water needs to be stronger than at present. Uncertainty in energy supply (power and diesel) has a detrimental effect on crop yields. This also affects water productivity.

The provision for crop insurance to reduce the risk of crop failure due to natural phenomena such as droughts and floods of differing severity requires serious consideration. This is of considerable importance given consequences of crop failure especially for the smaller and marginal farmers.

There needs to be significant strengthening of the linkages involving education extension and research. This is absolutely vital for awareness building and sensitization on resource use and resource conservation. The overwhelming dietary dependency on rice needs a rethink. However, this is a long-term phenomenon given that food habits are an integral part of the socio-cultural milieu. Reduction in dietary dependency on rice and more toward pulses, for example, could be significantly water-saving and at the same time more nutritious. This could be achieved through a proper awareness building about the dietary changes.

The above by no means represents an exhaustive list of options. However, it embodies some of the major options that Bangladesh needs to purse in order to sustain land and water productivity.

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