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Environmental constraints and profitability relationships in agriculture: a case study of wheat farming in Bangladesh

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ABSTRACT

This paper attempts to measure the influence of environmental constraints on profitability and resource use in agriculture by utilizing a survey data of 293 wheat farmers from three regions of Bangladesh. Analysis is based on a profit function, where the selected variables representing environmental constraints were incorporated as additional fixed factors. Results revealed that environmental constraints have a significant influence on both profitability and farmers' resource allocation decisions. Output supply as well as input demands were significantly affected by land suitability and other environmental constraints (i.e., a combination of poor soil fertility, pest and weed infestation, and weather variation). The policy implications include development of wheat varieties that are suitable for low lying and/or marginal areas, are resistant to insect and pest attacks, and can withstand weather variations. Also, soil fertility improvement through soil conservation and crop rotation, improvement in managerial practices through extension services, and strengthening of research-extension link will improve profitability.

Key words: Environmental constraints; Land suitability, Wheat farming; Profit-function analysis; Bangladesh.

JEL Classification: Q12, O13, C31

1. INTRODUCTION

Agriculture is characterized by its environmental, behavioural, and policy dimensions (Clapham, 1980). Agricultural intensification, particularly the adoption of modern agricultural technology (e.g., chemical fertilizers, pesticides, etc.), is often blamed for contamination of water, loss of genetic diversity and deterioration of soil quality (Pretty, 1995). However, some of the most significant environmental problems in resource poor areas, such as, soil degradation, biocide resistance in pests, adverse weather, can in turn affect agricultural production systems directly as well (Clapham, 1980). Farmers' production performance, and hence profitability, does not only depend on the physical resources and technology available to them, but also on the existing environmental constraints. For example, Sherlund et al., (2002) claimed that the prevalence of production inefficiency in agriculture (i.e., producing at a level lower than that is technically feasible) may partly be due to the consistent omission of variables representing environmental production conditions in farm production analysis, which was also supported by Rahman and Hasan (2008). We postulate that omission of variables representing environmental constraints not only affect technical efficiency in production, but may also affect profitability as well as resource allocation decisions of the farmer, which in turn has implication for sustaining agriculture and its growth. Rahman and Parkinson (2007) concluded that soil fertility status (i.e., level of available N, P and K in the soil) has a significant influence on both productivity and farmers' resource allocation decisions in Bangladeshi rice farming system. Kamruzzaman et al., (2006) and Rahman (2003) showed that soil quality has a significant positive influence on economic efficiency of wheat and rice production in Bangladesh, respectively. Similarly, Sidhu and Baanante (1981) noted that soil pH is the most important environmental variable which has a strong negative influence on wheat supply in Indian Punjab. Even farmers' environmental awareness of modern agricultural technology has an influence on their resource allocation decisions. For example, Rahman (2005) claimed that farmers' perception of the environmental factors significantly affect their resource allocation decisions. He noted that Bangladeshi farmers, who are aware of the adverse environmental impacts of modern agricultural technology adoption, use significantly lower amounts of all inputs in order to avoid further environmental damage.

Given this backdrop, the aim of this study is to examine the level and influence of environmental constraints on profitability and resource allocation decisions of Bangladeshi wheat farmers. This is done by including two variables representing environmental constraints (i.e., land suitability and a composite index of "other environmental constraints") in standard farm economic analysis by adopting the framework of Rahman and Parkinson (2007), Rahman (2005) and Sidhu and Baanante (1981).

The paper proceeds as follows. The next section briefly describes the unique features of the crop under study, i.e., wheat in Bangladesh. Section 3 describes the analytical framework, study areas and the data. Section 4 presents the results. The final section concludes and draws policy implications,

2. WHEAT IN BANGLADESH: GROWTH, PRODUCTIVITY AND CONSTRAINTS

Among the cereals, wheat is the second most important crop in Bangladesh agriculture and has been expanding rapidly since the 1990s. For example, wheat area in Bangladesh has increased steadily from only 125.6 thousand ha in 1971 to 832.4 thousand ha in 2000 but then declined sharply reaching only 479.1 thousand ha in 2006. Similarly, wheat production increased almost 17 folds from 110 thousand tons in 1971 to 1,840 thousand tons in 2000 and then declined sharply to 735.5 thousand tons in 2006. The corresponding yield level also increased from 0.9 t/ha in 1971 to 2.2 t/ha in 2000 and then fell to 1.5 t/ha in 2006 (Rahman and Hasan, 2009).

One unique feature of wheat in Bangladesh is 100% adoption of modern varieties as opposed to rice. Also, the use rate of modern inputs (i.e., inorganic fertilizers and pesticides) in wheat production is very high. Nevertheless, wheat is also one of the crops which are most sensitive to variation in the production environment. For example, there was a worldwide reduction in wheat production during late 2000 largely due to production failure, particularly in the southern hemisphere blamed at adverse weather conditions (Allen, 2008) resulting in a serious price hike in 2007-08. Rahman and Hasan (2009) also noted that the sharp fall in Bangladesh wheat area and production since 2001 is largely due to adverse weather conditions characterized with short spell of cold days and day-night temperature variations during the grain filling stage. They also attribute competition of limited land between high-value non-cereal crops and wheat grown during the same winter months (the *Rabi* season) as another important reason.

Research into the constraints of wheat production in Bangladesh by wheat agronomists during 1988 to 1990 revealed that a host of natural as well as managerial factors affect wheat yield. The reduction in wheat yield is estimated at: (a) 23–42% due to foliar diseases; (b) 8–16% due to soil pathogens; (c) 25–46% due to farmers' fertilizer doses (which is lower than the recommended doses); (d) 2.1% and 33.7% due to lack of irrigation under high- and low- fertility situations; and (e) late seeding at the rate of 1.3% per day of delay after November 30th (Ahmed and Meisner, 1996). On-Farm Research Division (OFRD) of Bangladesh Agricultural Research Institute (BARI) reported that there is still a yield gap of 41–61% between farmers' practice and the recommended package of the research station. Wheat yield with recommended package is 3.2 t/ha whereas actual production at the farm level varies between 1.3 to 1.9 t/ha (OFRD, 2001).

Nevertheless, the best practice farmers can produce a yield of 2.8 t/ha when compared with 1.9 t/ha by the average farmers, thereby, revealing a 29% yield gap (Hasan, 2005). Such a yield gap between the best practice farmers and the average farmers amounts to a loss of 25% of gross margin (Tk. 9,875/ha or US$169/ha). We postulate that although this yield gap could be due to a host of factors, one of the most important one is the environmental constraints, thereby, affecting profitability as well as competitiveness of Bangladeshi wheat farmers.

3. METHODOLOGY

3.1 Selection of the study area and sample farmers

Wheat is cultivated almost all over the country, though the intensity of planted area and land suitability are not equal in all regions. Selection of the study area was conducted by first constructing a wheat area index for each greater district[1]. The wheat area index for the *j*th district is expressed as:

$$WI_j = (Area_j / GCA_j) * 100, \quad (5)$$

where *WI* is the wheat area index, *Area* is the wheat area and *GCA* is the gross cropped area. Based on this index, wheat growing regions were classified into three levels of intensity: high intensity ($WI > 8.0\%$), medium intensity ($4.0\% \leq WI \leq 8.0\%$), and low intensity areas ($WI < 4.0\%$).

A multistage sampling procedure was adopted to select the sample farmers. First, three wheat growing regions (two from high intensity areas – Dinajpur and Rajshahi, and one from

[1] Although there are 64 districts in Bangladesh, most of the secondary data are still reported at the level of these 21 former greater districts.

medium intensity areas – Jamalpur) were selected purposively[2]. The selected three districts/regions[3] together cover 31% of the total wheat area of the country (Table 1). Also, each selected district belong to different agro-ecological zones (AEZ) of Bangladesh, namely, AEZ-3, AEZ 11 and AEZ-9, respectively[4]. Dinajpur is located in the north-west, Rajshahi in the mid-west and Jamalpur in the mid-north of Bangladesh. In the second stage, one *upazila* (sub-district) from each district and one union from each *upazila* were selected at random. Next, three *mouzas* (one from each union) were selected at random for primary data collection from the farm households. However, due to an insufficient number of households in one *mouza*, a fourth *mouza* was also selected at random to fulfil the required sample size. In the third stage, a number of steps were followed to select the households to ensure a high level of representation. At first, a sampling frame of wheat growing holdings was constructed with assistance from the village leaders, record book kept at the union council office and other key informants. The list included the names of household heads and their land holdings in the selected *mouzas*. These farm holdings were then stratified into three standard farm-size categories commonly adopted in Bangladesh (e.g., Hossain, 1989). Then, a total of 293 wheat producing households were selected following a stratified random sampling procedure. Two sets of structured questionnaires were administered. These questionnaires were pre-tested prior to finalization. The survey covered wheat growing period from November 2003 to April 2004.

[INSERT TABLE 1 HERE]

[2] The low intensity area is excluded because it is assumed that wheat production has limited potential in these districts.

[3] In this study the term district and region are used interchangeably to emphasize the large spatial variation between our study areas.

[4] There are a total of 29 agro-ecological zones which cut across many of the 21 greater districts/regions.

3.2 Modelling influence of environmental constraints on farmers' resource allocation decisions

A profit function approach is adopted to examine the influences of environmental constraints on farmers' resource allocation decisions. A profit function has a duality relationship with the underlying production function. An advantage of a profit function model is that it is specified as a function of prices and fixed factors which are exogenous in nature and, therefore, are free from possible endogeneity problem associated with a production function model. Furthermore, we are interested in measuring responsiveness of farmers to changes in prices of inputs and output as well as fixed factor endowments including variables representing environmental constraints. Therefore, a profit function model is more appropriate for this study.

The basic assumption is that farm management decisions can be described as static profit maximization. Specifically, the farm household is assumed to maximize 'restricted' profits from growing wheat, defined as the gross value of output less variable costs, subject to a given technology and given fixed factor endowments. In this context, the selected environmental variables were treated as the 'state-of-nature' variables and added into the analysis following the approach adopted by Sidhu and Baanante (1981) and Rahman and Parkinson (2007). Our *a priori* expectation is that output will be adversely affected by environmental constraints. However, its impact on input use levels cannot be determined *a priori*.

3.3 Variables representing environmental constraints

The assumption underlying the inclusion of environmental constraints in estimating the parameters of the profit function is that they are fixed in nature and are exogenously determined. Two variables were selected to account for environmental constraints. These are: (a) an index of land suitability (i.e., in terms of elevation); and (b) a composite index of other environmental constraints. Farmers were asked to provide their own account of his/her crop yield loss (in percentage) due to each specific environmental constraint. The constraints include insect and pest attacks, weed infestations, weather variations (drought or storm), and poor soil fertility status. The index was then constructed by aggregating all the individual estimates of yield loss percentages due to each of the aforementioned factors (see Table 2). The index value ranges from 0 to 7 indicating substantial yield loss. Also, significant negative correlation was observed between wheat profits per ha and the indices of land suitability ($r = -0.28$, $p<0.001$) as well as "other environmental constraints" ($r = -0.34$, $p<0.001$), respectively, thereby justifying inclusion of these variables in standard farm economic analysis.

3.4. The empirical model

The general form of the translog profit function, dropping the subscript for the farm, is defined as:

$$\ln \pi' = \alpha_0 + \sum_{i=1}^{4} \alpha_i \ln P'_i + \tfrac{1}{2} \sum_{i=1}^{4} \sum_{h=1}^{4} \gamma_{ih} \ln P'_i \ln P'_h + \sum_{i=1}^{4} \sum_{k=1}^{4} \delta_{ik} \ln P'_i \ln Z_k$$

$$+ \sum_{k=1}^{4} \beta_k \ln Z_k + \tfrac{1}{2} \sum_{k=1}^{4} \sum_{j=1}^{4} \theta_{kj} \ln Z_k \ln Z_j + \varepsilon \qquad (1)$$

where

π' = restricted profit (total revenue less total cost of variable inputs) normalized by price of output (P_y),

P'_i = price of the ith input (P_i) normalized by the output price (P_y),

i = 1, fertilizer price (taka kg^{-1})

= 2, labour wage (taka day^{-1})

= 3, animal power price (taka animal pair-$days^{-1}$)

= 4, seed price (taka kg^{-1})

Z_k = quantity of fixed input,

k = 1, area under wheat (ha farm^{-1})

= 2, irrigation (taka farm^{-1})

= 3, land suitability (index number farm^{-1})

= 4, other environmental constraints (index number farm^{-1})

ε = random error

ln = natural logarithm

α_0, α_i, γ_{ih}, β_k, δ_{ik}, *and* θ_{kj}, are the parameters to be estimated.

The corresponding factor share equations are expressed as,

$$S_i = -\frac{P_i X_i}{\pi'} = \frac{\partial \ln \pi'}{\partial \ln P'_i} = \alpha_i + \sum_{h=1}^{4} \gamma_{ih} \ln P'_h + \sum_{k=1}^{4} \delta_{ik} \ln Z_k \qquad (2)$$

$$S_y = \frac{P_y X_y}{\pi'} = 1 + \frac{\partial \ln \pi'}{\partial \ln P_y} = 1 + \sum_{i=1}^{4} \alpha_i + \sum_{i=1}^{4}\sum_{h=1}^{4} \gamma_{ih} \ln P'_h + \sum_{i=1}^{4}\sum_{k=1}^{4} \delta_{ik} \ln Z_k \qquad (3)$$

where S_i is the share of ith variable input, S_y is the share of output, X_i denotes the quantity of input i and Y is the level of rice output. Since the variable input and output shares form a singular system of equations (by definition S_y - ΣS_i = 1), one of the share equations, the output share, is dropped and the profit function and four variable input share equations are estimated jointly using Seemingly Unrelated Regression Estimation[5] (SURE) procedure. The joint estimation of

[5] The SURE procedure, proposed by Zellner (1962), is a generalisation of a linear regression model containing several equations. The SURE estimation procedure is efficient particularly when the error terms of the individual equations are assumed to be correlated as compared with separate estimation of each equation of the system. Since the input share equations in our model are derived from the profit function, it is logical to assume that the error terms of the profit function and all the share equations are correlated, and therefore, the choice of SURE procedure is more appropriate.

the profit function together with factor share equations ensures consistent parameter estimates (Sidhu and Baanante, 1981).

Among the regularity properties of the profit function specified in equation (1), homogeneity was automatically imposed because the normalized specification was used. The monotonicity property of a translog profit function model holds if the estimated output share is positive (Farooq et al., 2001) which was found in our case. The symmetry property was tested by imposing cross-equation restrictions of equality on the corresponding parameters between the profit function and the four factor demand equations. The test failed to reject the restrictions, thereby confirming that the symmetry property also holds and the sample farms do maximize profit with respect to normalized prices of the variable inputs (Sidhu and Baanante, 1981). The convexity property was assumed to hold and was not tested.

Fertilizer, labour and animal power, and seed are the four major inputs that are essential in producing any crop and contribute significantly to total cost of production (Rahman, 1999). Total cultivated land devoted to wheat is expected to have a significant positive association with the quantities of input demanded. Also, studies on Bangladesh found land to be the most important input in crop production with a very high level of output elasticity (Wadud and White, 2000). Lack of access to irrigation has been identified as one of the principal reasons for stagnation in rice cultivation (Rahman and Thapa, 1999) but it is also important for wheat as highlighted by Ahmed and Meisner (1996). Finally, land suitability and environmental constraints variables were included to examine their independent influence on farmers' resource allocation decisions.

4. RESULTS

Summary statistics of the variables used in the profit function model are presented in

Table 2. One main limitation and/or criticism in applying a profit function model in a cross-section of data is the lack of variation in input and output prices. The geographical dispersion of the sampled farmers and imperfections in the input markets in Bangladesh ensure adequate variability in prices at any given point in time. However, a valid test is required to confirm this intuition. In our sample, wheat price varied from Tk 11.00–12.25 per kg (wheat price + straw price); fertilizer price (average price of 5 types of fertilizers used) varied from 7.32 to 9.69 per kg; labour wage varied from Tk 52–65 per person day; animal power price varied from Tk 42–65 per animal pair-days; and seed price varied from Tk 12–14 per kg, respectively. A formal F-test for differences in the prices of wheat, fertilizers, labour wage, animal power services and seeds among the regions rejected the null-hypothesis of 'no-difference' at 1% level of significance, thereby confirming that significant price variations exist in our sample, and hence, the application of the profit function model is justified (Table 3).

Table 4 presents estimates of the profit function model estimated jointly with four variable input share equations. Twenty-five of the total 44 parameters are significantly different from zero at 10% level at least in the profit function. Significance of the interaction terms indicates non-linearity in the production structure, which justifies use of a flexible translog model instead of a more restrictive Cobb-Douglas model.

[INSERT TABLES 2, 3 and 4]

The parameter estimates of the profit function model are used to estimate the elasticities with respect to variable input demand and output supply (Table 5). Most of the elasticity estimates (34 out of 45) are significantly different from zero at 10% level at least, thereby indicating that the wheat farmers are responsive to change in prices as well as fixed factor endowments including environmental constraints.

One of the key policy variables of interest is the output price. The supply response of farmers to a rise in wheat price is positive and almost elastic as expected. A 1% increase in wheat price will increase its supply by 0.95%. A positive response of output supply (rice or wheat) to its price has been common in Asia since the 1970s. For example, supply response of HYV rice in Bangladesh is estimated at 0.36 (Rahman and Shankar, 2009), Basmati rice in Pakistan Punjab at 0.27 (Farooq *et al*., 2001), and Mexican wheat in Indian Punjab at 0.63 (Sidhu and Baanante, 1981). On the other hand, a rise in wheat price will result in a significant increase in demand for all inputs, the highest effect being on seed demand. A 1% increase in wheat price will increase seed demand by 2.5% followed by labour demand by 2.3%, respectively, implying substantial rural employment opportunities.

All own price elasticities are negative, consistent with theory although they lie in the inelastic range except labour price. A 1% reduction in labour wage will increase labour demand by 1.1%, which is substantial.

[INSERT TABLE 5 HERE]

Among the fixed factor endowments, supply response to an expansion in land area is high, as expected. A 1% increase in land area will increase wheat supply by 0.79% which is comparable to those obtained by Rahman and Parkinson (2007), Farooq et al., (2001), and Sidhu and Baanante (1981). Among the inputs, response to an expansion in land area is also high. A 1% increase in land area under wheat will increase seed demand by 0.88%, labour demand by 0.72%, fertilizer demand by 0.70% and animal power demand by 0.60%. Irrigation does not have any significant influence on output supply and input demand. This is because although irrigation is applied to wheat crops to some extent, it is not as critical as in the case of rice cultivation, particularly, for the *Boro* rice grown in the winter season which is totally dependent on supplementary irrigation.

Table 5 also shows influence of the environmental constraints on both output supply and input demand. Both the land suitability and the other forms of environmental constraints have a significantly negative influence on wheat supply, consistent with our *a priori* expectation. The impact of poor land suitability is much higher though. A 1% decline in land suitability will reduce wheat supply by 0.72% whereas a 1% increase in "other environmental constraint" will reduce wheat supply by 0.16%. Poor land suitability also significantly reduce demand for fertilizers and animal power services but not labour or seed use. On the other hand, "other environmental constraints" consistently reduce demand for all inputs significantly. This may occur when farmers realize that the environmental constraints have struck the crop in one form or the other, and therefore, they tend to economise on the use of inputs in order to prevent further loss in terms of operational costs in addition to the inevitable loss from reduced crop yield.

5. DISCUSSION AND POLICY IMPLICATIONS

The inclusion of variables representing "environmental constraints" in economic analysis of farmers' resource allocation decision is uncommon, although in reality farmers' production structure is highly likely to be influenced by both economic as well as natural/environmental factors. The present study attempted to integrate these two strands of scientific enquiry into farmers' decision making processes. Therefore, we incorporated two key "environmental constraint" variables and examined their influence on resource allocation decisions while explicitly controlling for farmers' responses to market indicators (i.e., the input and output prices) as well as other fixed resource endowments (i.e., land and irrigation).

On the whole, changes in market price of inputs and output have significantly influenced farmers' resource use and productivity (wheat supply) as expected. A rise in wheat price will increase its supply as well as demand for all four inputs, particularly a high impact on labour use. This rise in labour demand in response to wheat price increase will lead to a redistribution of gains accrued from modern agriculture to landless labourers via wages, an argument in favour of widespread diffusion of modern agricultural technology in the first place. With respect to the variable inputs, increase in their prices will depress wheat supply, although the magnitude of responsiveness is very low and is in the inelastic range.

Among the conventional fixed factors, the role of land area in influencing productivity and resource use remains dominant. This is expected in a land-scarce country like Bangladesh where average farm size is only 0.60 ha (BBS, 2001). Therefore, an increase in the availability of land will dramatically increase wheat supply and will result in consequent increase in the use of variable inputs. Once again, landless labourers will gain access to the profit generated by wheat production via higher demand for hired labour owing to an increase in wheat area. However, the influence of irrigation on wheat supply and input demand is quite limited. This is because wheat requires substantially less water and also irrigation is largely applied at a fixed rate (mostly at a pre-determined number of frequencies and hours in a season) and not very sensitive to farm size. In fact, wheat provides highest returns in non-irrigated zones and in areas that are unsuitable for *Boro* rice (dry winter irrigated rice) and represents the most efficient use of domestic resources when inputs and outputs are assigned economic prices (Morris et al., 1996).

Returning to our variables of key interest, we see that both variables representing environmental constraints have a significantly negative influence on output supply, thereby pointing towards their importance in raising farm productivity, profitability and hence competitiveness of these Bangladeshi wheat farmers. The results show that unsuitable land has a much larger impact on reducing wheat supply as compared to other environmental constraints.

Nevertheless, both are significant determinants of reducing input demands as well. Fifteen percent of our sampled farmers produced wheat in lands that are low lying and is not suitable for optimum production. Also, a substantial 97% of farmers reported some form of “other environmental constraints”. Of these, the top two factors cited are “pest and insect attack” and “weed infestation” reported by 75% and 68% of the farmers, respectively. The remaining two factors, “weather variations (storm or drought)” and “poor soil fertility status” were reported by 42% and 31% of the farmers, respectively.

The overarching policy implication of this study is that the elimination or a reduction of environmental constraints can exert a significantly positive impact on the production process of wheat leading to an increase in crop yield, thereby raising farmers’ income, profitability and competitiveness in the market. The farmers surveyed here were operating on a range of land suitability and are therefore, suffering from significant reduction in potential productivity and profitability. Therefore, research effort should be geared towards developing varieties that are suitable for marginal areas. Evidence suggests that wheat production in marginal lands accounts for 25% of global production and that research innovation has led to significant improvement in yield growth in these areas, particularly in drought and high temperature environments (Lantican et al., 2003).

The top three important elements included in the “index of other environmental constraint” variable were yield losses due to “pest attack”, “weed infestations” and “weather variations”. Possible measures to eliminate these constraints are by: (a) developing varieties that are both pest and weed resistant as well as weather resistant; (b) improving managerial practices of the farmers; and (c) adopting environmentally friendly technologies, e.g., Integrated Pest Management (IPM) technology. The first option requires not only to develop varieties at the research stations but also to disseminate them effectively through improving research-extension link. Bangladesh has a dedicated Wheat Research Centre established in early 1970s and so far developed 24 wheat varieties (Rahman and Hasan, 2009). However, the new varieties that are developed (some of which are pest and disease resistant, but not so much on weather resistance) remain confined at the research stations. Dominance of only one variety at the farm-level which was released 27 years ago[6] clearly points toward the need to develop research-extension link. Improvements in managerial practices of farmers also require improved extension and training support. Evidence shows that the farmers who have access to extension services perform significantly better in terms of earning actual profit from modern rice cultivation in Bangladesh (Rahman, 2003). The Indonesian agriculture has benefited greatly from the adoption of environment friendly technology programmes. Since 1989 the Indonesian government promoted IPM technologies along with a banning order of 57 types of pesticides (to mark a shift from the input intensive Green Revolution period), which not only saw a continued yield growth in rice but also a reduction in the use of detrimental chemicals (i.e., pesticides, weedicides, fungicides and inorganic fertilizers) (Mariyono et al., 2010). Adoption of similar policies through concerted effort by the government could also provide similar benefits to Bangladeshi agriculture.

The fourth element in the "index of other environmental constraint" is yield loss due to "poor soil fertility status". This constraint may be addressed through adopting soil conservation practices and/or improving crop rotation practices (e.g., including soil health enhancing crops, such as pulses and oilseeds, in the system). Of the nine total cropping patterns observed among the sampled farmers, most followed rice-based cropping. Only two patterns included jute in the

[6] Although 24 modern varieties of wheat have been released since 1974, '*Kanchan*' released in 1983, remains the most popular choice. In fact, 94% of our sample farmers used only '*Kanchan*'.

system and none included any pulse or oilseed crops, which is potentially highly detrimental to soil health in the long run. Therefore, government policies should be geared towards devising an effective strategy that promotes soil conservation measures to ensure and sustain future productivity potential of these soils, a finding also noted by Rahman and Parkinson (2007) for rice farmers in Bangladesh.

The challenges to realize all of these policy options are formidable. However, a boost in wheat production could significantly curb dependence on rice as the main staple in Bangladeshi diet, which is a goal worth pursuing.

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Table 1. Selection of the study area and sample size

Study area	Area selection criteria			Farm size categories			
	Wheat area index (WI in %)	Intensity Rank (Out of 21 greater districts)	% of total wheat area	Large farms (2.0 ha and above)	Medium farms (1.01 to <2.0 ha)	Small farms (up to 1.0 ha)	All categories
Dinajpur	16.94	2	16	33 (92)	29 (86)	39 (122)	101 (300)
Rajshahi	9.12	4	11	19 (32)	32 (49)	52 (228)	103 (309)
Jamalpur	7.55	6	4	8 (11)	25 (46)	56 (178)	89 (235)
All area	-	-	31	60 (135)	86 (181)	147 (528)	293 (844)

Notes: Figures in parentheses indicate sampling frame.

Source: BBS (2001), and field survey, 2004.

Table 2. Price variation across regions

Prices	Measurement	Dinajpur	Rajshahi	Jamalpur	F-statistic	p-value
Wheat price	Taka kg^{-1}	11.90	11.78	11.35	47.68	0.000
Fertilizer price	Taka kg^{-1}	9.64	9.83	9.11	149.65	0.000
Labour wage	Taka person-day^{-1}	64.58	63.20	59.29	61.99	0.000
Animal power price	Taka pair-day^{-1}	56.16	56.67	52.12	22.85	0.000
Seed price	Taka kg^{-1}	13.83	13.82	13.29	34.68	0.000

Notes: Based on One-way Analysis of Variance using Generalized Linear Modelling technique.

[a] = Exchange rate of USD 1.00 = Taka 63.76 in 2004-05 (BB, 2010)

Table 3. Description, measure and summary statistics of the variables

Name	Description	Measurement	Mean	Standard deviation
PW	Profit from wheat production	Taka[a]	1817.29	1070.56
Y	Quantity of wheat output	Kg	315.96	165.88
X_F	Quantity of fertilizers	Kg of nutrients	19.28	9.85
X_W	Quantity of labour	Person-days	13.35	6.23
X_M	Quantity of animal power services	Animal pair-days	2.62	2.88
X_S	Quantity of seeds	Kg	21.67	11.28
Y_W	Wheat price	Taka kg^{-1}	11.69	0.46
F	Fertilizer price	Taka kg^{-1}	9.55	0.42
W	Labour wage	Taka person-day^{-1}	62.49	4.01
M	Animal power price	Taka pair-day^{-1}	55.11	5.39
S	Seed price	Taka kg^{-1}	13.66	0.56
A	Land area cultivated	Hectare	0.13	0.06
I	Irrigation	Taka	89.57	63.59
L	Land suitability	Indexed (1 = Medium high land – most suitable; 2 = High land – suitable; 3 = Low land – not suitable)	1.49	0.74
E	Other environmental constraints[b]	Indexed (1 = 1 – 10%, 2 = 11 – 20%, 3 = 31 – 40%, 4 = 41 – 50%, 5 = 51 –	2.40	1.14

60%, 6 = 61 – max., of crop yield)

Note: [a] = Exchange rate of USD 1.00 = Taka 63.76 in 2004-05 (BB, 2010)

[b] = Figures are based on farmer's own account of his/her crop loss due to each specific constraints. The constraints include yield losses due to insect and pest attack, weed infestation, weather variations (drought or storm), and poor soil fertility status.

Table 4. Restricted parameter estimates of the translog profit function and factor share equations

Variables	Parameters	Coefficients	t-ratio
Profit Function			
Constant	α_0	7.4588	14.77***
lnP'_F	α_F	-0.3113	-3.37***
lnP'_W	α_W	-0.4497	-2.20**
lnP'_M	α_M	-0.0161	-0.17
lnP'_S	α_S	-0.3299	-5.54***
$½(lnP'_F \; x \; lnP'_F)$	γ_{FF}	-0.1691	-2.64***
$½(lnP'_W \; x \; lnP'_W)$	γ_{WW}	-0.2044	-1.68*
$½(lnP'_M \; x \; lnP'_M)$	γ_{MM}	-0.1707	-4.11***
$½(lnP'_S \; x \; lnP'_S)$	γ_{SS}	-0.0864	-2.30**
$lnP'_F \; x \; lnP'_W$	γ_{FW}	0.1265	2.55***
$lnP'_F \; x \; lnP'_M$	γ_{FM}	-0.0602	-2.02**
$lnP'_F \; x \; lnP'_S$	γ_{FS}	0.0958	1.82*
$lnP'_W \; x \; lnP'_M$	γ_{WM}	0.0935	2.74***
$lnP'_W \; x \; lnP'_S$	γ_{WS}	0.0596	1.83*
$lnP'_M \; x \; lnP'_S$	γ_{MS}	-0.0011	-0.06
$lnP'_F \; x \; lnZ_A$	δ_{FA}	0.0348	4.98***
$lnP'_F \; x \; lnZ_I$	δ_{FI}	-0.0004	-0.19
$lnP'_F \; x \; lnZ_L$	δ_{FL}	-0.0059	-0.72

Variables	Parameters	Coefficients	t-ratio
$lnP'_F \times lnZ_E$	δ_{FE}	0.0020	1.25
$lnP'_W \times lnZ_A$	δ_{WA}	0.0692	3.46***
$lnP'_W \times lnZ_I$	δ_{WI}	0.0749	11.78***
$lnP'_W \times lnZ_L$	δ_{WL}	-0.0656	-2.85***
$lnP'_W \times lnZ_E$	δ_{WE}	-0.0014	-0.32
$lnP'_M \times lnZ_A$	δ_{MA}	0.0426	4.48***
$lnP'_M \times lnZ_I$	δ_{MI}	0.0085	2.81***
$lnP'_M \times lnZ_L$	δ_{ML}	-0.0393	-3.61***
$lnP'_M \times lnZ_E$	δ_{ME}	-0.0030	-1.41
$lnP'_S \times lnZ_A$	δ_{SA}	-0.0038	-0.75
$lnP'_S \times lnZ_I$	δ_{SI}	0.0221	13.47***
$lnP'_S \times lnZ_L$	δ_{SL}	-0.0366	-6.09***
$lnP'_S \times lnZ_E$	δ_{SE}	-0.0008	-0.67
lnZ_A	β_A	0.6806	2.89***
lnZ_I	β_I	-0.1010	-1.09
lnZ_L	β_L	-0.6127	-1.48
lnZ_E	β_E	-0.1534	-2.06**
$½(lnZ_A \times lnZ_A)$	θ_{AA}	-0.0591	-0.87
$½(lnZ_I \times lnZ_I)$	θ_{II}	0.0314	3.23***
$½(lnZ_L \times lnZ_L)$	θ_{LL}	0.3510	1.55
$½(lnZ_E \times lnZ_E)$	θ_{EE}	-0.0155	-3.12***

Variables	Parameters	Coefficients	t-ratio
lnZ_A x lnZ_I	θ_{AI}	-0.0132	-0.54
lnZ_A x lnZ_L	θ_{AL}	-0.0579	-0.71
lnZ_A x lnZ_E	θ_{AE}	-0.0144	-0.92
lnZ_I x lnZ_L	θ_{IL}	0.0755	1.41
lnZ_I x lnZ_E	θ_{IE}	0.0090	0.92
lnZ_L x lnZ_E	θ_{LE}	-0.0487	-0.81
Fertilizer share equation			
Constant	α_F	-0.3113	-3.37***
lnP'_F	γ_{FF}	-0.1691	-2.64***
lnP'_W	γ_{FW}	0.1265	2.55**
lnP'_M	γ_{FM}	-0.0602	-2.02**
lnP'_S	γ_{FS}	0.0935	2.74***
lnZ_A	δ_{FA}	0.0348	4.98***
lnZ_I	δ_{FI}	-0.0004	-0.19
lnZ_L	δ_{FL}	-0.0059	-0.72
lnZ_E	δ_{FE}	0.0020	1.25
Labor share equation			
Constant	α_W	-0.4497	-2.20**
lnP'_F	γ_{FW}	0.1265	2.55**
lnP'_W	γ_{WW}	-0.2044	-1.68*
lnP'_M	γ_{WM}	0.0958	1.82*

Variables	Parameters	Coefficients	t-ratio
lnP'lnP'_S	γ_{WS}	0.0596	1.83*
lnZ_A	δ_{WA}	0.0692	3.46***
lnZ_I	δ_{WI}	0.0749	11.78***
lnZ_L	δ_{WL}	-0.0656	-2.85***
lnZ_E	δ_{WE}	-0.0014	-0.32
Animal power share equation			
Constant	α_M	-0.0161	-0.17
lnP'_F	γ_{FM}	-0.0602	-2.02**
lnP'_W	γ_{WM}	0.0958	1.82*
lnP'_M	γ_{MM}	-0.1707	-4.11***
lnP'_S	γ_{MS}	-0.0011	-0.06
lnZ_A	δ_{MA}	0.0426	4.48***
lnZ_I	δ_{MI}	0.0085	2.81***
lnZ_L	δ_{ML}	-0.0393	-3.61***
lnZ_E	δ_{ME}	-0.0030	-1.41
Seed share equation			
Constant	α_S	-0.3299	-5.54***
lnP'_F	γ_{FS}	0.0935	2.74***
lnP'_W	γ_{WS}	0.0596	1.83*
lnP'_M	γ_{MS}	-0.0011	-0.06
lnP'_S	γ_{SS}	-0.0864	-2.30**

Variables	Parameters	Coefficients	t-ratio
lnZ_A	δ_{SA}	-0.0038	-0.75
lnZ_I	δ_{SI}	0.0221	13.47***
lnZ_L	δ_{SL}	-0.0366	-6.09***
lnZ_E	δ_{SE}	-0.0008	-0.67
F-statistic		293.76***	
Observations		293	

Note: *** Significant at 1 % level (p<0.01)

** Significant at 5 % level (p<0.05)

* Significant at 10 % level (p<0.10)

Variables P_i' = normalised variable input prices, and Z_k = fixed inputs.

Subscripts F = fertilizer price, W = labour wage, M = animal power price, S = seed price, A = land area cultivated, I = irrigation, L = land suitability, and E = other environmental constraints.

Based on the estimation of the restricted translog profit function and four variable input share equations with across-equation restrictions (symmetry) and linear homogeneity imposed.

Table 5. Estimated elasticities of translog profit function

	Wheat price	Fertilizer price	Labour wage	Animal power price	Seed price	Land area	Irrigation	Land suitability	Other environmental constraints
Wheat supply	0.9466	-0.2161	-0.5607	-0.1118	-0.2129	0.7861	-0.0093	-0.7169	-0.1594
	(11.74)***	(-6.23)***	(-8.19)***	(-3.93)***	(-6.51)***	(3.36)***	(-0.10)	(-1.74)*	(-2.14)**
Fertilizer demand	2.0569	-0.4474	-0.1022	0.0979	-0.6052	0.6955	0.0433	-0.7608	-0.1699
	(6.24)***	(-1.57)	(-4.90)***	(0.69)	(-3.89)***	(2.95)***	(0.47)	(-1.84)*	(-2.27)**
Labour demand	2.2548	-0.4751	-1.1123	-0.3699	-0.2974	0.7157	-0.1094	-0.6559	-0.1649
	(8.19)***	(-4.90)***	(-5.03)***	(-3.66)***	(-4.86)***	(3.03)***	(-1.18)	(-1.58)	(-2.21)**
Animal power	1.2933	0.1351	-1.0894	-0.1683	-0.1708	0.6028	-0.0092	-0.7529	-0.1726
demand	(3.93)***	(0.69)	(-3.66)***	(-0.94)	(-1.65)*	(2.52)***	(-0.09)	(-1.82)*	(-2.30)**
Seed demand	2.5310	-0.7707	-0.8741	-0.1706	-0.6692	0.8773	-0.0886	-0.4019	-0.1725
	(6.51)***	(-3.89)***	(-4.86)***	(-1.65)*	(-3.31)***	(3.73)***	(-0.95)	(-0.93)	(-2.30)**

Note: Elasticity estimates computed at mean values.

Figures in parentheses are t-ratios.

*** Significant at 1 % level (p<0.01)

** Significant at 5 % level (p<0.05)

* Significant at 10 % level (p<0.10)