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Energy productivity and efficiency of maize accounting for the choice of growing season and environmental factors: an empirical analysis from Bangladesh

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ABSTRACT

The paper evaluates sustainability of maize cultivation in Bangladesh in terms of energy use while taking into account factors affecting choice of the growing season and farmers' production environment using a sample selection framework applied to stochastic frontier models. Results reveal that the probability of growing winter maize is influenced positively by gross return, irrigation, subsistence pressure, soil suitability and temperature variability whereas extension contact influences choice negatively. Significant differences exist between winter and summer maize regarding yield, specific energy, net energy balance, energy use efficiency and technical energy efficiency although both systems are highly sustainable and efficient. The energy output from winter maize is 199,585 MJ/ha which is 53.9% higher than the summer maize output of 129,701 MJ/ha. Also, energy input use of winter maize is 110.6% higher than the summer maize. Energy inputs from mechanical power, seeds, fertilizers and organic manures significantly increase energy productivity of winter maize whereas only mechanical power influences summer maize productivity. However, temperature variation and rainfall significantly reduce energy productivity of summer maize. Policy implications include investments in soil conservation and irrigation, development of weather resistant varieties and raising maize price will boost maize cultivation in Bangladesh, a highly sustainable production technology.

JEL Classification: O33, Q18, and C21.

Keywords: Energy productivity and efficiency, season selection decision, stochastic production frontier, maize, Bangladesh

1. Introduction

Energy use in agriculture has become a prominent concern because of the rapid depletion of non-renewable sources of energy, rapid population growth and environmental degradation, especially in the developing economies. The concern is particularly high for countries reliant on Green Revolution technology to promote agricultural growth which in turn is largely dependent on fossil fuels, e.g., inorganic fertilizers, pesticides and mechanization (particularly for supplementary irrigation and land preparation).

The agricultural sector of Bangladesh is a significant contributor to national income (14.9% of Gross Domestic Product) and foreign exchange earnings (35.0% of total) and a major source of employment generation (48.1% of total) [1, 2, 3]. The country also has one of the lowest land-person ratios in the world of only <0.2 ha [1]. Consequently, the agricultural system is operating at a high cropping intensity of 179.0% [1]. Even then, it has been increasingly realized that economic development in Bangladesh cannot be achieved without making a real breakthrough in the agricultural sector [4].

Energy use in Bangladesh agriculture has been modest in the past but has increased rapidly in recent years. For example, the energy intensity in the agricultural sector has jumped from only 1.78 in 2000 to 11.31 in 2008 [5] adding further a crisis to the existing problem of acute energy deficiency in the economy. Knowledge of the available energy resources and consumption pattern in agriculture is important in order to support energy policies that are conducive to developing efficient crop production systems [6], particularly for energy deficient economies such as Bangladesh. This is because there is a clear association between increase in energy inputs and crop productivity [6].

Although rice is the main staple crop in Bangladesh, maize is gaining importance as a third crop after wheat covering 0.9% and 1.7% of the gross and net cropped area, respectively [1]. Interestingly, the yield of the composite and/or hybrid varieties of maize released from the Bangladesh Agricultural Research Institute ranges from 5.5–12.0 t/ha which are well above the world average yield of 5.2 t/ha [7]. Maize has now positioned itself as the first among the cereals in terms of yield rate (5.7 t/ha) as compared to rice (2.8 t/ha) and wheat (2.2 t/ha) [1].

Maize in Bangladesh is grown both in winter and summer time, although the former is the dominant pattern. However, it is not clear as to why farmers choose to grow either summer maize or winter maize but not both even though maize provides higher returns as compared to rice [4] and wheat [8]. The general perception is that the yield of winter maize is higher whereas the price of summer maize is higher, which has major implications with respect to total revenue generated from growing maize in different seasons. We postulate that a host of socio-economic factors as well as the production environment within which the farmers operate may be responsible for making the choice of growing season. It is well known that the production environment significantly influences productivity and efficiency [9, 10], but we are interested here to check whether environmental factors also influence the choice of the growing season of crops.

A number of studies have evaluated energy productivity and energy use efficiency of various crops including maize [6, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26]. However, generally these studies concentrated on evaluating energy productivity and energy use efficiency by applying an accounting approach [6, 11, 12, 15, 22, 25]. Some of the recent studies have utilized a non-parametric programming approach, specifically Data Envelopment Analysis (DEA), to examine the energy efficiency of crops [13, 14, 16, 19, 20, 21, 24]. Although the advantage of DEA is that it does not require assumption of any functional form to specify the production technology, it suffers from a well-known limitation that all measurement errors are included as inefficiency, thereby leading to upward bias in the computation of inefficiency levels. A few studies have also used a parametric and/or econometric approach to examine energy productivity and efficiency of crops, but their procedures were largely confined to deterministic models which assume perfect efficiency in the production process [17, 18, 23]. This is not a realistic assumption given the evidence that farmers in developing economies operate within a mean technical efficiency range of 72.4–80.6% under various farming systems (e.g., rice, maize, dairy farming, whole farm, etc.) [27]. Recently, Rahman and Barmon [26] have used the stochastic input distance function model to estimate energy productivity and efficiency of 'gher' (prawn-rice-fish) farming system in Bangladesh. It is important to analyse a cropping system or a production technology with respect to energy performance because if the system produces more energy as outputs than it uses as inputs, then the system can be deemed sustainable in the long run.

Given this backdrop, the main aim of this study is to evaluate the sustainability of maize production technology. We address this objective in terms of the energy that the system produces as output and the level of energy it uses as inputs. Since maize is grown in both the winter and summer seasons and the technology differs between them, we jointly evaluate the decision to choose maize growing season (i.e., winter vs. summer maize) and its energy productivity and efficiency at the level of individual producers, additionally controlling for the environmental factors that affect performance. We adopt the framework developed by Greene [28, 29] that removes sample selection bias in stochastic frontier models which is inherent in these types of studies. The bias arises because rational farmers choose between summer and winter maize depending on the socio-economic as well as environmental factors within which they have to operate. Therefore, in this model of rational season selection decision, using observations from a single season alone (be it summer or winter maize), is likely to produce biased estimates of the production function which will be carried onto biased estimates of production efficiency. It is also necessary to remove such bias in the sample selection procedure while estimating productivity and efficiency. In other words, one must control for the self-selection actions of the farmers choosing either winter or summer maize although all farmers are exposed to similar socio-economic and environmental conditions. To our knowledge, no single study examining the energy productivity and efficiency of field crops, including those cited above, have addressed these issues in their analyses. This is our contribution to the existing literature on the energy performance analysis of agricultural crops.

The paper is organized as follows: section 2 describes the methodology and the data; section 3 presents the results; and the final section concludes and draws policy implications.

2. Methodology

2.1 Analytical framework

The analytical framework consists of two approaches: (a) an accounting approach that provides some basic measures of energy performance commonly seen in the energy literature [11, 12, 13, 15, 17, 22, 25]; and (b) an econometric estimation of the energy productivity and technical energy efficiency of maize production using a stochastic production frontier approach jointly determined with the choice of growing season as well as controlling for the environmental factors within which farmers operate.

2.2.1 The energy accounting approach

Standard energy input output analysis [11, 12, 13, 15, 17, 22, 25] is used to estimate some basic measures of the summer and winter maize farming systems. These are defined as [12]:

Energy use efficiency = Energy output (MJ per ha) /Energy input (MJ per ha) (1)

Energy productivity = Output (kg per ha)/Energy input (MJ per ha) (2)

Specific energy = Energy input (MJ per ha)/Output (kg per ha) (3)

Net energy = Energy output (MJ per ha) – Energy Input (MJ per ha) (4)

We applied standard energy coefficients from the existing published literature [6, 11, 12, 13, 14, 15, 22, 25] for conversion. Specifically, production energy for power tiller and shallow tube wells (which are not available in the literature) were calculated as follows [12]:

$$M_{pe} = (GM_p)/(TW) \tag{5}$$

where M_{pe} is the energy of the power tiller per unit area (MJ per ha); G is the mass of the power tiller (kg); M_p is the production energy of the power tiller, (MJ per kg); T is the economic life (hour); and W is the effective field capacity (ha per hour).

The diesel energy requirement was determined on the basis of fuel consumption (litre per hour). The data were converted into energy units and expressed in MJ per ha. Fuel consumption was computed as [12]:

$$FC = P_m.R.SFC \tag{6}$$

where FC is the fuel consumption (litre per hour); P_m is the machine power (kW); R is the loading ratio (decimal); and SFC is the specific fuel consumption (0.25 litre kW per hour). Table 1 presents the energy coefficients used in this study including literature sources.

[TABLE 1 ABOUT HERE]

2.2.2. Stochastic production frontier with sample selection

We assume that the farmers decide to choose between summer and winter maize to maximize profits based on their socio-economic circumstances and the environmental constraints they face. The decision of the *i*th farmer to choose winter maize is described by an unobservable selection criterion function, I_i*, which is modelled as a function of gross return, factors representing farmers' socio-economic circumstances and the environmental factors within which farmers operate. However, the selection criterion function is not observed. What we observe instead is a dummy variable, *I,* which takes a value of 1 for winter maize farms and 0 otherwise. The model is specified as:

$$I_i{*} = \boldsymbol{\alpha}'\mathbf{z}_i + w_i, I_i = 1 \ \ (I_i{*} > 0) \tag{7}$$

where ***z*** is a vector of exogenous variables explaining the decision to grow winter or summer maize, α is a vector of parameters and w is the error term distributed as $N(0,\sigma^2)$.

The production performance of both winter maize and summer maize farmers are modelled using an extended Cobb-Douglas stochastic production frontier function[1].

The models are written as follows:

Winter maize growers: $y_i = \boldsymbol{\beta}'\mathbf{x}_i + \boldsymbol{\delta}'\mathbf{e}_i + v_i - u_i \quad \textit{if and only if} \quad I_i = 1$ (8)

Summer maize growers: $y_i = \boldsymbol{\beta}'\mathbf{x}_i + \boldsymbol{\delta}'\mathbf{e}_i + v_i - u_i \quad \textit{if and only if} \quad I_i = 0$ (9)

where **x** represents physical energy inputs and **e** represents environmental factors, y represents energy output level, *β'* and *δ'* are the parameters; and *v* is the two sided random error, independent of the *u*, representing random shocks, such as exogenous factors, measurement errors, omitted explanatory variables, and statistical noise; and *u* is a non-negative random variable associated with inefficiency in production, assumed to be independently distributed as a zero-truncated normal distribution, $u = |U| \ with \ U \sim N[0, \sigma_u{}^2]$.

In this model of 'sample selection' it is assumed that *w* in (7) is correlated with *v* in (8) and/or (9), and therefore, (*v, w*) are distributed as bivariate normal distributions with $[(0,0),(\sigma_v{}^2, \rho\sigma_v, 1)]$. The vectors (*y, **x** and **e***) are observed when *I* = 1.

Development of the estimator for this model is detailed in Greene [28, 29]. We only report the final log likelihood function to be estimated [27]:

$$\log L_s = \sum_i \log \frac{1}{R} \sum_{r=1}^{R} \left\{ d_i \left[\frac{2}{\sigma_u} \phi\left(\frac{\beta'\mathbf{x}_i + \delta'\mathbf{e}_i + \sigma_v v_{ir} - y_i)}{\sigma_u} \right) \Phi\left(\frac{\alpha'\mathbf{z}_i + \rho v_{ir}}{\sqrt{1-\rho^2}} \right) \right] + (1 - d_i) \left[\Phi\left(\frac{-\alpha'\mathbf{z}_i - \rho v_{ir}}{\sqrt{1-\rho^2}} \right) \right] \right\} \quad (10)$$

L_s is the contribution of the individual *i* to the simulated log likelihood, *R* is the number of replications for the simulation which is 500, ϕ is the standard normal pdf, Φ is the standard

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[1] The Cobb-Douglas specification is widely used in production frontier studies [10]. Moreover, Kopp and Smith [31] suggest that the choice of functional form has a limited effect on efficiency.

normal cdf, β' are the slopes in the frontier production function for the conventional inputs, δ' are the slopes in the frontier production function for the environmental variables, σ_v is the standard deviation of the symmetric component of the compound disturbance in the stochastic frontier model v, σ_u is the standard deviation of the efficiency random variable u, α' are the coefficients in the season selection equation, ρ is the correlation between the error term in the season selection equation and v in the stochastic frontier model. Since the integral of this function does not exist in a closed form, Greene [28, 29] proposes computation by simulation. The model is estimated using NLOGIT Version 4 [30].

2.2. Study areas and the sample farmers

Maize is cultivated almost all over the country with varying intensity because of unequal levels of land suitability across regions. Therefore, a maize area index for each of the 21 greater/former districts is computed. The maize area index for the jth district is expressed as:

$$MAI_j = (Area_j / GCA_j) \times 100 \qquad (11)$$

where MAI is the maize area index, $Area$ is the maize area and GCA is the gross cropped area. In other words, it represents the share of maize area in GCA. Based on this index, maize growing regions were classified into three levels of intensity: high intensity ($MAI>1.0$), medium intensity ($0.50<MAI<1.0$), and low intensity areas ($MAI<0.5$).

The sampled farmers were selected following a multistage sampling procedure. First, for winter maize, three areas were selected based on MAI rank and percentage of total winter maize area. The selected regions are Kushtia, Bogra and Dinajpur which covered 59% of the total winter maize area of the country. A similar exercise was repeated for summer maize. The selected regions are Dhaka, Bogra and Dinajpur which covered 64% of the total summer maize area of the country (Table 2). Second, one current/new district was chosen from each aforesaid selected greater district based on the share of maize area and ease of communication. Then, one upazila (sub district) from each new district and one union from each upazila were selected purposively. Then, six villages (one from each union) were selected randomly for the collection of primary data. Third, a number of steps were followed to select the households to ensure a high level of representation. At first, a list of all maize growing farmers was collected from the Department of Agricultural Extension (DAE). Then, these farm holdings were stratified into three standard farm-size categories commonly adopted in Bangladesh [10]. Then, a total of 300 winter maize and 150 summer maize producing households were selected following a standard stratified random sampling procedure (Table 2). A structured and pre-tested questionnaire was administered: to collect in depth information from the sampled farmers by making three visits covering each of the crop seasons. The first visit was done just after the seed was sown, the second visit was done immediately after completion of all intercultural operations and the last visit was done after the harvesting and threshing of the crop. The formal survey for data collection covered the maize growing year 2006-07. For winter season maize, the data were collected from November 2006 to April 2007, while for summer season maize the data were collected from February to July 2007.

[Insert Table 2 here]

2.3. The variables

Two sets of variables are used, one for the probit season selection model and the other for the stochastic production frontier model. The first column of Table 3 presents the variables including definitions and measurements. The dependent variable in the probit equation is the farmers' season selection criterion. This is a binary variable that takes the value of 1 if a plot is planted with winter maize and 0 otherwise. The explanatory variables include, gross return from maize (Taka[2]/ha), farm size (ha), irrigation intensity (Taka/ha), farmer's education (completed years of schooling), farmer's age (years), farming experience (years), subsistence pressure (persons per household), and extension contact (1 = if had extension or training, 0 otherwise). Also, three environmental variables, the land suitability index, the soil suitability index and temperature stability are included.

In the stochastic production frontier model for winter maize, a total of six physical energy inputs were included. These are mechanical power, human labour, seeds, inorganic fertilizers, chemicals (pesticides/insecticides), and organic manure. In addition, the four environmental variables included in the model are the land suitability index, the soil suitability index, total rainfall during the growing season[3], and temperature stability (i.e., mean temperature range calculated as maximum – minimum temperature) during the growing season[4] (^{0}C). The summer maize production frontier model excludes two physical energy inputs, chemicals and organic manures, as these were not applied by any farmer.

We expect a positive relationship between energy output and variables representing land suitability and soil suitability but the influence of the other two environmental variables (rainfall and temperature) are unclear.

3. Results

3.1. Socio-economic characteristics and environmental factors

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[2] Taka refers to Bangladesh currency. The official exchange rate was 1 USD = Taka 69.06 during the year 2006-07 [32].

[3] Data on total monthly rainfall is collected from the Bangladesh Meteorological Department (BMD). We have used data for corresponding months of the maize growing season (November – April for winter maize and February – July for summer maize) that most closely match with the sampled regions.

[4] BMD also collects mean monthly maximum and minimum temperature disaggregated at regional level.

Table 3 presents a comparison of the socio-economic circumstances and environmental constraints faced by winter and summer maize farmers. The interesting finding is that most of the socio-economic circumstances (i.e., age, education, and farming experiences) between winter and summer maize farmers are similar except that the former tends to be large farmers. The summer maize growers received a significantly higher level of extension and/or training support which is surprising. This may be due to the fact that one of the summer maize regions (Manikganj) is very close to the capital Dhaka and, therefore, enjoyed better extension support. However, significant differences exist with respect to all the environmental variables between winter and summer maize growers. Rainfall is significantly higher during the summer period as expected. Variability in temperature is, however, significantly higher in the winter season. This may be due to unusual cold spells that occur only sporadically for a short period in a sub-tropical country like Bangladesh. Winter maize is grown on significantly better land types and soils than summer maize, the reason for which is not very clear.

[Insert Table 3 here]

3.2 Energy use levels in maize farming

The last panel of Table 3 presents energy use levels between summer and winter maize farming with significant differences between these two seasons. The energy output of winter maize is 53.9% higher than summer maize which confirms the general perception of the higher yield of winter maize. The physical yield of winter maize is 7,988 kg/ha and summer maize is 5,191 kg/ha (Table 4). The main reason for such a higher yield of winter maize may be due to a significantly higher use of chemical as well as organic fertilizers. The winter maize yield is somewhat closer to maize yield in Iran estimated at 6,808 kg/ha [16] but far above the yield level reported for India [6]. Also, energy input use is significantly higher for winter maize farmers except for human energy. Among the energy inputs, the dominant one is inorganic fertilizers accounting for 54.5% and 48.0% of total input use in winter and summer season, respectively. The comparable figures for fertilizer use in crops are wheat at 45.4% [6], potatoes at 46% [8], rice at 36% [15] and maize at 33% [16]. However, Bangladeshi farmers also use organic fertilizer (i.e., composed cow dung) up to 15.0% of total input use in winter maize which is closely comparable to 20% level used in India [6].

Table 4 presents some basic indicators of energy performance of maize production using the energy accounting approach, commonly seen in the energy literature [6, 11, 12, 13, 14, 15, 22, 25]. Results from Table 4 clearly establish that both summer and winter farming pass the test of sustainability when evaluated in terms of energy use. The net energy balance for winter and summer maize are estimated at 170,753 MJ per ha and 116,014 MJ per ha, respectively. These figures are substantially higher when compared with energy balance of maize at 51,347 MJ per ha in Iran [16] and 67,177 MJ per ha in India [6].

However, energy use efficiency is higher for summer maize at 9.56 as compared to winter maize at 7.07. This is because summer maize producers do not use chemicals and organic manures and also cut back on fertilizers to some extent, thereby, improving energy use efficiency. These levels of energy use efficiency are comparable to India at 7.07 [6] but substantially higher than Iran at 2.59 [16]. Given the evidence in Table 4, we can firmly conclude that maize farming for both seasons in Bangladesh is highly sustainable, which is very encouraging.

[TABLE 4 ABOUT HERE]

3.3. Determinants of the choice of maize growing season

The estimation of the results of the season selection function is presented in Table 5. The model fit is quite satisfactory as is evident from the model diagnostic tests and the accuracy of prediction. The Chi-squared test statistic result confirms that the inclusion of these variables in explaining farmers' season selection decision is strongly justified ($p<0.01$). Next, the value of McFadden R-squared statistic is estimated at 0.65 which is high. Most importantly, about 90% of the observations were accurately predicted which is very satisfactory (i.e., 90% of actual 1s and 0s on the dependent variable are correctly predicted using these variables). Also, 55% of the variables specified in the model are significantly different from zero at least at the 10% level. We see that the gross return from maize production, irrigation and subsistence pressures are the important determinants of choosing winter maize. However, extension contact depresses the choice of winter maize which is rather surprising. Among the environmental variables, soil suitability and variation in temperature significantly influence the choice of winter maize cultivation, thereby, establishing our a priori expectation that environmental factors within which the farmers operate do play an important role in their decision making processes (Table 5).

[Insert Table 5 here]

3.4. Energy productivity of maize farming

Table 6 presents the results of the stochastic production frontier models corrected for sample selection bias for winter and summer maize. The model diagnostic tests reveal that both model fits are quite satisfactory. The estimates of σ_u and σ_v are significantly different from zero at least at the 10% level in both models. Also, the coefficient on the ρ variable is significantly different from zero at the 1% level in both models confirming that serious sample selection bias exists, thereby, justifying use of the sample-selection framework in our analysis. In other words, this finding confirms that estimation using observations from only a single season of maize producers (either winter or summer maize producers) will provide biased estimates of the production frontier, which will then be carried onto the biased estimates of technical energy efficiency scores as well.

Energy productivity of winter maize increases with an increase in energy from mechanical power, seeds, fertilizers and organic manures, as expected. Since a Cobb-Douglas model is used, the coefficients on the variables can be read directly as output elasticities. We see that energy from mechanical power has the highest elasticity value of 0.16 implying that a one percent increase in the use of mechanical power will increase the energy productivity of maize by 0.16%. The next important determinant of winter maize energy productivity is fertilizer with an elasticity value of 0.12. However, it is surprising to see that only energy from mechanical power is the significant determinant of summer maize productivity with an elasticity value of 0.11.

With respect to the influence of environmental factors on maize energy productivity, we see a very different outcome. There is no influence of the environmental factors on winter maize productivity whereas both rainfall and temperature variability significantly reduce summer maize productivity. This perhaps explains why winter maize cultivation is the dominant pattern in the country. A possible explanation is that winter weather conditions in Bangladesh are more or less stable, particularly with respect to rainfall, whereas the summer season is very unpredictable. Total rainfall is very high and variable with occasional storms during the summer season. For example, the mean total rainfall during the summer season is 1376.00 mm with a standard deviation of 314.12 whereas the mean total rainfall during the winter season is 200.33 mm with a standard deviation of 63.54. Overall, our results clearly establish that it is important to take into account the influence of environmental constraints within which farmers operate as they exert significant influence on crop productivity although these are largely ignored in the literature with few exceptions [9, 10].

[Insert Table 6 here]

3.5. Technical energy efficiency of maize farmers

The summary statistics of technical energy efficiency scores for winter and summer maize farmers, corrected for sample selection bias, are presented in Table 7. The mean energy efficiency is estimated at 0.93 and 0.95 for winter and summer maize farmers, respectively, implying that the maize farmers are operating at a very high level of technical efficiency.

Nevertheless, the summer maize farmers are more efficient than the winter maize farmers (mean difference 2 points, $p<0.01$). The distribution of energy efficiency is also within a very narrow range, implying that most farmers are operating at a very high level of efficiency. Our estimates of technical energy efficiency are closely comparable to estimates for rice at 0.90 in Iran [21], 0.92 for rice in India [14], and 0.85 for soybean in Iran [20].

[Insert Table 7 here]

4. Conclusions and policy implications

The principal objective of this study is to determine sustainability of maize farming in Bangladesh which is growing quite rapidly in recent years. We address this question by evaluating this farming technology in terms of energy use. We apply both the commonly used energy accounting approach as well as an econometric approach to address our research objectives. Since maize is grown in both seasons, we have evaluated energy productivity and efficiency while controlling for the factors that influence farmers' decisions to choose maize growing season (i.e., winter vs summer) as well as additionally controlling for the environmental factors within which farmers operate. The model diagnostic tests confirmed that serious sample selection bias exists for both winter and summer maize growers, thereby, justifying use of our chosen econometric approach.

Our results show that maize farming in both seasons is highly sustainable. The summer maize farmers are more efficient although the net energy balance generated by winter maize farmers is 35% higher than that of the summer maize farmers. Also, the winter maize farmers use significantly higher levels of energy inputs except human labour. Significant differences exist with respect to all the environmental factors between the winter and summer growing seasons.

The results confirm that both socio-economic and environmental factors significantly determine the probability of choosing winter maize. Gross return, irrigation and subsistence pressure influence the decision to choose winter maize. Also, soil suitability and temperature variation significantly influence winter maize choice. Energy from mechanical power, fertilizers, seeds and organic manures significantly increase winter maize energy productivity whereas only mechanical power influences summer maize productivity. Rainfall and temperature variability significantly influence summer maize productivity. The mean level of technical energy efficiency of these self-selected winter and summer maize farmers are estimated at 93% and 95% implying that maize farmers in Bangladesh are performing extremely well.

The policy implications are clear. Investment in improving soil suitability and the development of weather resistant varieties will significantly induce farmers to adopt winter maize technology which is a sustainable farming system as it produces substantially more energy than it uses. Similarly, price policies to keep the maize price high during the winter season will boost farm returns and will increase adoption of winter maize farming. The maize price during the summer season is estimated at Tk 468.7 per ton as compared to Tk. 357.74 per ton during the winter season. In fact, the low price of maize was ranked as one of the major constraints by these maize growers. Also, availability of irrigation will boost winter maize cultivation. Although the realization of these policy measures is quite challenging, an increase in maize production could significantly curb dependence on rice as the main staple in the Bangladeshi diet as well as conserve energy.

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Table 1. Energy coefficients used for maize cultivation

Variables	Unit	Energy equivalents (MJ per unit)	References
Inputs			
Maize seed	kg	14.70	[7]
Power tiller (land preparation)	litre	62.20	Calculated
Cowdung/organic manure	kg	1.00	[33]
Irrigation (diesel)	litre	56.31	[11]
Pesticides	litre	120.00	[11]
Nitrogen (N)	kg	66.14	[11]
Phosphorus (P_2O_5)	kg	12.44	[11]
Potassium (K_2O)	kg	11.15	[11]
Sulphur (S)	kg	1.12	[11]
Other fertilizers (zinc and boron)	kg	29.19	[7]
Outputs			
Maize grain	kg	14.70	[7]
Stover/stem	kg	18.00	[7]

Table 2. Selection of the study area and sample size

Greater district	New district	Area selection criteria			Farm size categories			
		Maize area index (MAI)	Intensity Rank (Out of 21 greater districts)	% of total maize 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
Winter Maize								
Kushtia	Chuadanga	2.31	1	31	27	39	34	100
Bogra	Bogra	0.92	3	17	18	34	48	100
Dinajpur	Dinajpur	0.45	5	11	27	37	36	100
All winter area		-	-	59	72	110	118	300
Summer maize								
Bogra	Bogra	0.58	2	25	4	11	35	50
Dinajpur	Thakurgaon	0.49	3	21	16	18	16	50
Dhaka	Manikganj	0.43	4	18	2	15	33	50
All summer area		-	-	64	22	44	84	150
Total sample		-	-	-	94	154	202	450

Source: BBS [34] and field survey, 2007.

Table 3. Energy inputs and outputs, socio-economic factors and environmental constraints of the winter and summer maize farmers.

Variables	Winter maize		Summer maize		Mean difference (WM-SM)	t-ratio
	Mean	Standard deviation	Mean	Standard deviation		
Socio-economic factors						
Gross return per ha (Taka[1]/ha)	72406.75	10010.11	57167.52	9057.50	15239.22***	16.07
Farm size (ha)	1.67	1.48	1.36	1.74	0.31*	1.84
Age of the farmer (years)	40.94	11.07	42.82	13.35	-1.88	-1.47
Education of the farmer (completed year of schooling)	5.44	4.35	5.12	4.23	0.32	0.75
Farming experience (years)	21.41	11.00	22.66	12.61	-1.25	-1.02
Subsistence pressure (persons per household)	5.43	2.28	4.81	1.69	0.63***	3.25
Extension/training contact (1 = if had training or extension contact, 0 otherwise)	0.48	--	0.57	--	-0.86*	1.70
Environmental constraints						
Index of land suitability (3 = highland/medium highland – most suitable; 2 = medium land – suitable; 3 = low land – not suitable).	1.97	0.23	1.84	0.39	0.13***	4.51
Index of soil suitability (4 = silt – most suitable; 3 = silt loam – highly suitable; 2 = clay loam – suitable; 1 = sandy – unsuitable)	3.31	0.57	3.04	0.26	0.27***	6.80
Temperature stability (mean temperature range, i.e.,	9.58	0.50	9.15	0.15	0.43***	13.86

maximum – minimum temperature) during the growing season (^{0}C)						
Precipitation during the growing season (mm)	200.33	63.54	1385.34	314.43	-1186.01***	-44.98
Energy inputs and outputs						
Maize energy output (MJ/ha)	117423.26	8251.71	76308.21	25011.42	41115.05***	25.75
Maize stover energy output (MJ/ha)	82162.04	5773.79	53393.70	17500.7	28768.55***	25.75
Mechanical power energy input (MJ/ha)	5934.60	987.73	4569.85	1324.39	1364.75***	12.17
Human labour energy input (MJ/ha)	2331.20	452.18	2289.93	592.68	41.27	0.81
Seed energy input (MJ/ha)	303.09	26.47	260.78	33.19	42.32***	14.51
Fertilizers energy input (MJ/ha)	15716.65	3085.4	6563.37	2616.12	9153.28***	30.77
Chemical energy input (MJ/ha)	220.50	264.11	0.00	0.00	--	--
Organic manure energy input (MJ/ha)	4326.28	4506.16	0.00	0.00	--	--
Observations	300		145			

Note: [1] = refers to Bangladeshi currency. Official exchange rate was 1 USD = Taka 69.06 during the year 2006-07 [32].

*** Significant at 1 percent level ($p<0.01$)

* Significant at 10 percent level ($p<0.10$)

Five observations from the summer maize farmers were removed due to incomplete information.

Source: Field survey 2007.

Table 4. Energy accounts in winter and summer maize cultivation

Measurements	Unit	Winter Maize	Summer maize	Mean difference (WM-SM)	t-ratio for mean difference
Energy input	MJ per ha	28832.33	13686.93	15145.40***	35.38
Energy output	MJ per ha	199585.30	129701.70	69883.59***	25.75
Maize yield	kg per ha	7988.00	5191.00	2796.90***	25.75
Specific energy	MJ per kg	3.61	2.77	0.90***	13.99
Energy use efficiency	-	7.07	9.56	-2.49***	-16.08
Energy productivity	kg per MJ	0.28	0.38	-0.10***	-16.08
Net energy	MJ per ha	170752.97	116014.77	54738.20***	21.32

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

Table 5. Parameter estimates of the probit season selection equation

Variables	Probit coefficients	
	Coefficient	**t-ratio**
Constant	-65.3509***	-4.40
Socio-economic factors		
Gross return per ha	0.0002***	8.45
Cost of irrigation	0.0003*	1.71
Maize area	-0.0853	-1.21
Age of the farmer	0.0041	0.23
Education of the farmer	0.0393	1.37
Experience in farming	-0.0019	-0.09
Subsistence pressure	0.2817***	4.62
Extension contact	-2.0134***	-6.49
Environmental constraints		
Index of land suitability	-0.3921	-0.43
Index of soil suitability	0.5272*	1.77
Temperature stability	5.6647***	3.70
Model diagnostics		
Log likelihood	-97.48	
McFadden R-squared	0.65	
Chi-squared	366.79***	

Degrees of freedom	11
Accuracy of prediction (%)	90.11
Number of total observations	445

Note: *** significant at 1 percent level ($p<0.01$);

* significant at 10 percent level ($p<0.10$)

Table 6. Parameter estimates of the stochastic production frontier model for winter and summer maize corrected for sample selection bias.

Variables	**Parameters**	**Stochastic production frontier model of winter maize**		**Stochastic production frontier model of summer maize**	
		Coefficient	**t-ratio**	**Coefficient**	**t-ratio**
Constant	α_0	9.1589***	18.02	88.1225	0.05
Physical energy inputs					
ln Mechanical power energy	β_1	0.1596***	5.60	0.1057*	1.90
ln Human labour energy	β_2	0.0142	0.49	-0.0179	-0.19
ln Seed energy	β_3	0.0889*	1.92	0.0923	0.72
ln Fertilizer energy	β_4	0.1196***	5.16	0.0007	0.02
ln Chemical energy	β_5	0.0023	1.36	--	--
ln Organic manure energy	β_6	0.0045***	3.78	--	--
Environmental constraints					
ln Land suitability	ω_1	0.1433	0.90	-0.8179	-0.01
ln Soil suitability	ω_2	-0.0019	-0.12	-0.0362	-0.42
ln Precipitation during the season	ω_3	-0.0174	-0.57	-2.4964***	-13.97
ln Temperature stability	ω_4	-0.0626	-0.39	-26.5202***	-11.83
Model diagnostics					
Log likelihood		353.39		98.81	
σ_u		0.0909***	7.73	0.0695*	1.65

σ_v	0.0395***	7.40	0.0889***	6.01
ρ (Sample selection bias, $\rho_{w,v}$)	0.8206***	2.80	0.9144***	4.59
Number of selected observations	300		145	

Note: *** significant at 1 percent level ($p<0.01$);

* significant at 10 percent level ($p<0.10$)

Table 7. **Distribution of technical energy efficiency scores of winter and summer maize farmers.**

	Winter maize	Summer maize
Efficiency levels		
Upto 85%	4.00	0.00
86 – 90%	17.70	3.40
91 – 95%	39.00	40.70
96% and above	39.30	55.90
Efficiency scores		
Minimum	0.80	0.86
Maximum	0.99	0.98
Mean	0.93	0.95
Standard deviation	0.04	0.02
Mean difference in efficiency score		-0.02***
t-ratio of mean difference		-3.90
Number of observations	300	145

Note: *** significant at 1 percent level ($p<0.01$).