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Productivity and soil fertility relationships in rice production systems, Bangladesh

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ABSTRACT

This paper presents an econometric analysis of the influence of soil fertility status on productivity and resource use in rice production utilizing survey data from 21 villages in three agro-ecological regions of Bangladesh. Detailed crop husbandry input-output data were collected from 380 paddy rice (*Oryza sativa*) farmers. Data collected included fertilizer, pesticide, labour, animal power services, irrigation, farm capital assets and rice yield. The soil fertility status in each region was determined by analysis of soil organic carbon, available nitrogen, phosphorus and potassium concentration. Analysis was based on a profit function, where the selected soil fertility parameters were incorporated as yield controlling variables. Results revealed that soil fertility has a significant influence on both productivity and farmers' resource allocation decisions. Output supply was significantly higher in fertile regions and input use was significantly lower. This observation indicates that in policy terms technological initiatives should be targeted at measures to identify areas of lower soil fertility so that inherent soil-based productivity restrictions can be minimized. In part this will be facilitated by the transfer of indigenous knowledge from farmers in higher productivity areas, thus increasing rice production and raising the competitiveness of Bangladeshi rice farmers.

Key words: Soil fertility, Rice production, Profit-function analysis, Bangladesh.

1. INTRODUCTION

Land is the most important natural resource that provides livelihood for the majority of people in Bangladesh. Agriculture accounts for more than 50% of national income and employs two-third of the labour force. The dominant sector is the field crop agriculture accounting for more than 60% of agricultural value added. Among the field crops, rice is the major staple crop, occupying 70% of the cropped area (BBS, 2001). Historically, being a food deficit country with an extremely unfavourable land-person ratio of only 0.06 ha, Bangladesh has pursued a policy of rapid technological progress in agriculture by promoting diffusion of a rice-based 'Green Revolution (GR)' technology package. As a result, land-use intensity increased sharply to 175% in 1999 from its initial level of 146% in 1969 (Rahman and Thapa, 1999; and BBS, 2001) with corresponding increase in input use. For example, use of chemical fertilizers increased six times during 1968–94 and use of pesticides increased three-fold in just one decade during 1982–92 (Rahman and Thapa, 1999). Consequently, total rice output grew at an annual rate of 2.2 % during 1965-87 and then declined to half the previous rate at 1.1 % during 1988-97 (Otsuka, 2000). In fact, the yield rate of modern rice steadily declined from 3.6 mt in 1969 to 2.4 mt in 1994 with an estimated annual rate of decline of 1.2% (Rahman, 2002), thereby confirming that productivity from GR technology is falling. It is believed that more than 65% of the total agricultural land is suffering from declining soil fertility and about 85% of net area suitable for cultivation has an organic matter below the minimum requirement (TFR, 1991). Soil analysis of 460 samples from 43 profiles from the same locations between 1967 and 1995 revealed a decline in fertility (Ali et al., 1997) although this decline in soil fertility has not been explicitly linked to GR technology. Baanante et al., (1993) noted that the present level of food crop production in Bangladesh takes up an estimated 0.93 mt of nutrients (N, P, K and S) from the soil annually. Widespread adoption of

GR technology was identified as a cause of significant soil degradation and declining crop yields in India (Singh, 2000; Yadav et al., 2000). Pimentel (1996) indicated that extensive use of fertilizers and pesticides to support the GR has caused serious public health and environmental damages worldwide, particularly in developing countries. Furthermore, it has been noted that continued, intensive production of rice has lead to yield reductions in some countries in Asia, explained in part by soil nutrient exhaustion (Doberman et al., 2002)

There is a large body of literature on GR covering several dimensions of this complex technology package, such as productivity, growth, employment and equity (e.g., Das, 2002; Rahman, 1999; Freebairn, 1995; Hazell and Ramasamy, 1991), but the interactions between soil fertility status and farmers' indigenous knowledge have been less well studied. Payton et al. (2003) identified that Bangladeshi farmers possess an intimate and sophisticated knowledge of soil properties and management problems. Ali (2003) concluded that "despite their lack of knowledge of soil genesis, soil morphology and soil chemistry, farmers were able to qualitatively identify major typology, properties, and productivity constraints of topsoil" (pp. 333). This paper examines resource allocation decisions made by the GR farmers of Bangladesh, a country that is particularly vulnerable in terms of food security. The specific aim was to provide a measure of responsiveness of selected soil fertility parameters with respect to the use of key production inputs and supply of output (rice) which will be useful for policy makers.

2. METHODOLOGY

2.1 Location and cropping in the study regions

Three of the intensive rice producing areas of Bangladesh, Jamalpur, Jessore and Comilla, were selected for this study. Jamalpur is located within Jamalpur Sadar Thana (central administrative sub-district), in the south-eastern part of Jamalpur district. The study area is 180 km northwest from Dhaka. Jessore is located in Manirampur Thana in the southern part of Jessore district, 290 km southwest from Dhaka. Comilla is located in Matlab Thana in the south-eastern part of Chandpur district, 120 km southeast from Dhaka.

An estimated 75% of the gross cropped area was under modern varieties of rice and wheat and 62% was under irrigation in the study regions during the crop year 1996. The cropping intensity (defined as the ratio of gross cropped area to net sown area multiplied by 100) of the sample farms is estimated at 172.8 (183.3 in Jamalpur, 178.2 in Jessore and 148.2 in Comilla region), which is very close to the national estimate of 173.2 for the year 1995/96 (BBS, 2001).

2.2 Data and Variables

The study is based on farm-level data for crop year 1996 collected from three agro-ecological regions of Bangladesh. The survey was conducted from February to April 1997. The specific selected regions were Jamalpur (representing wet agroecology), Jessore (representing dry agroecology), and Comilla (representing both wet agroecology and an agriculturally developed area). A multistage random sampling technique was employed to locate the districts, then the *Thana* (sub districts), and then the villages in each of the three sub districts and finally the sample households. A total of 380 households from 21 villages (174 households from eight villages of Jamalpur Sadar *Thana*, 100 households from six villages of Manirampur *Thana* and 106 households from seven villages of Matlab *Thana*) form the sample for the study. Detailed input-output data were collected for modern varieties of rice produced in a crop year. The dataset also includes information on level of soil fertility determined from soil samples collected from representative locations in the study villages.

2.3 Soil sampling and analysis

Data on physical and chemical properties of soils from the selected farmers' fields were collected to evaluate the fertility status of the soil and to examine inter-regional differences between the study areas. Soils were mapped in the three study areas at series level. Soil series were distinguished following a process of detailed chemical and physical characterisation using standard procedures (SRDI, 1991), based on assessment of inherent variability. SRDI (1991) employed ranges and thresholds for key soil parameters (texture, colour, structure, pH, organic carbon, available phosphorus, potassium and iron) to define and map separate soil series. Therefore soil series as mapped were used to select five distinct sampling locations in each region, giving a total of 15 composite soil samples in total, representing 15 different soil series. Soils were collected from random locations within rice-plots within the survey households. Soil sub-samples were collected from the 0 – 200 mm cultivated horizon at each of 3 – 5 random locations within a selected plot, and were then thoroughly mixed to give a composite sample. Samples were air dried prior to analysis.

As a part of a wider project (Rahman, 1998), soil samples were analyzed for (1) soil organic carbon content, (2) available potassium, (3) available phosphorus, (4) available nitrogen, (5) available sulphur, (6) available zinc, (7) soil texture, and (8) soil pH. In this paper, data are presented for the key soil chemical parameters that are directly modified by routine fertilizer practice and are less subject to inter-season and spatial variability, viz. soil organic carbon content, available phosphorus, available potassium, and available nitrogen. Soil organic carbon (SOC) content was measured using the Walkley-Black rapid titration method. Available phosphorus (P) was extracted using Truog's extraction method and determined colorimetrically by spectrophotometer. Available potassium (K) was extracted by neutral normal ammonium acetate solution and determined by Gallenkamp flame photometer. Available (mineral) nitrogen (N) was determined using the micro-Kjeldahl method. Full methodological details of all soil analyses are given in PCARRD (1980). Soil organic carbon, available N, P and K concentrations were converted into topsoil mass per unit area (kg ha^{-1}) assuming a soil bulk density of 1.0 Mg m^{-3} for the cultivated soil horizon (0.00 – 0.20 m).

2.4 Modelling influence of soil fertility status on farmers' resource allocation decisions

A profit function approach is adopted to examine the effect of soil fertility status on resource allocation decisions. The basic assumption is that farm management decisions can be described as static profit maximization. Specifically, the farm household was assumed to maximize 'restricted' profits from growing modern rice, 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 soil fertility parameters from the test results were treated as 'state-of-nature' variables and added into the analysis following the approach adopted by Sidhu and Baanante (1981).

2.4.1 Soil fertility variables

In order to create these 'state-of-nature' variables for each of the sampled households, we extrapolated our soil sample results taken from representative farm-plots to farm households whose plots belong to the same village and fall within the same soil series. The justification for adopting this approach is two-fold. First, in preparing the Land and Soil Resource Use Guideline at *Thana* (sub-district) level, which includes a soil fertility map based on representative soil sampling, the Soil Development Research Institute utilized the soil series classification system

(SRDI, 1991). They noted that a particular soil series is named/determined according to a number of characteristics, e.g., texture, structure, colour, organic matter content, and soil pH. Also, in general, chemical properties of soils within a given soil series were observed to be similar, as soils mapped within each series was formed from the same parent material. Therefore it was assumed that each soil series possessed similar properties. Hence, one can expect similar results from other soil samples collected from the same soil series. Although it should be noted that there are obvious limitations to this extrapolation, given that many soil properties are dynamic and depend not only on parent material but also on recent management history, which was found to be similar across surveyed farmers. As such, one can use replicate information on soil properties collected from one location of a given soil series to other locations falling within the same soil series simply by referring to the soil fertility map (SRDI, 1991). Second is the nature of the paddy fields from where these samples were taken. We took soil samples from rice plots of surveyed households, which were located within a large continuous block of land area designated as paddy fields where most of the farmers of that village have rice plots. Furthermore, cross-referencing of these blocks of paddy fields with the soil fertility map revealed that they all fell within the same soil series. Therefore, extrapolation of soil fertility parameters to surveyed households with rice plots falling within the same soil series was not expected to pose any significant limitation to the interpretation of soil analysis data.

2.4.2. The empirical model

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

$$\ln \pi' = \alpha_0 + \sum_{i=1}^{4} \alpha_i \ln P'_i + \tfrac{1}{2} \sum_{i=1}^{4} \sum_{h=1}^{4} \gamma_{ih} \ln P'_i \ln P'_h + \sum_{i=1}^{4} \sum_{k=1}^{7} \delta_{ik} \ln P'_i \ln Z_k$$

$$+\sum_{k=1}^{7}\beta_k \ln Z_k + \tfrac{1}{2}\sum_{k=1}^{7}\sum_{j=1}^{7}\theta_{kj} \ln Z_k \ln Z_j + \varepsilon \qquad (1)$$

where

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

P'_i = price of the *i*th 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, pesticide price (taka 100 g^{-1} of active ingredients)

Z_k = quantity of fixed input,

k = 1, area under modern rice varieties (ha farm^{-1})

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

= 3, farm capital (taka farm^{-1})

= 4, soil organic carbon content (kg ha^{-1})

= 5, soil available phosphorus (P), (kg ha^{-1})

= 6, soil available potassium (K), (kg ha^{-1})

= 7, soil available nitrogen (N), (kg ha^{-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,

$$S_i = -\frac{P_i X_i}{\pi'} = \frac{\partial \ln \pi'}{\partial \ln P'_i} = \alpha_i + \sum_{h=1}^{4}\gamma_{ih} \ln P'_h + \sum_{k=1}^{7}\delta_{ik} \ln Z_k \qquad (2)$$

$$S_y = \frac{P_y X_y}{\pi'} = 1 + \frac{\partial \ln \pi'}{\partial \ln P_y} = 1 + \sum_{i=1}^{4} \alpha_i + \sum_{i=1}^{4} \sum_{h=1}^{4} \gamma_{ih} \ln P'_h + \sum_{i=1}^{4} \sum_{k=1}^{7} \delta_{ik} \ln Z_k \qquad (3)$$

where S_i is the share of *i*th 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 $S_y - \Sigma S_i = 1$), 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 (SURE) procedure. The joint estimation of 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 (3), 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 (Wall and Fisher, 1987 cited in 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, are the three major inputs that are essential in producing any crop and contribute significantly to total cost of production (Rahman, 1999). Owing to diffusion of GR, pesticide also became an integral part of the system, although past studies consistently omitted this essential input, except for some in recent years, such as Tzouvelekas et al. (2001) and Wadud and White (2000). Total cultivated land devoted to modern rice is expected to have significant positive association with 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 GR diffusion in Bangladesh (Rahman and Thapa, 1999). Use of farm capital, other than land, is also important to a large extent in field crop production.

Inclusion of soil-related 'state-of-nature' variables is a rather uncommon practice in farm economic analysis (Sidhu and Baanante, 1981). Moreover, given the emerging concerns regarding sustainability of food production, declining soil fertility and other environmental problems arising from GR adoption (e.g., Shiva, 1991; Pimentel, 1996; Rahman and Thapa, 1999; and Singh, 2000), inclusion of these variables in economic decision making is becoming more and more important. The key soil fertility variables used in this analysis were soil organic carbon and available N, P and K, all of which are core components of soil fertility (Parkinson, 2003). Soil organic carbon (SOC) is an important soil fertility indicator because it has a major influence on biophysical and biochemical soil function. Soil pH was not included because the range of pH values observed was restricted, and fell within the optimum range suitable for rice production environment (SRDI, 1991). Our *a priori* expectation was that input use levels of chemicals (i.e., fertilizers and pesticides) would be lower in fertile regions due to a higher nutrient status of the soils.

3. RESULTS

Summary statistics of the variables used in the profit function model are presented in Table 1. Soil fertility variables included in the analysis were SOC, indicative of inherent soil physical, chemical and biological fertility, and available soil N, P and K, the three macronutrients that are yield limiting in rice production systems (Wijnhoud *et al.*, 2003). Table 2 presents the estimates of the profit function estimated jointly with four variable input share equations. Thirty-one of the total

78 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 1 AND 2 HERE]

The parameter estimates of the profit function model are used to estimate the elasticities with respect to variable input demand and output supply (Table 3). Most of the elasticity estimates (43 out of 60) are significantly different from zero at 10% level at least indicating that modern rice farmers are responsive to change in prices as well as fixed factor endowments including soil fertility variables.

One of the key policy variables of interest is the output price. The supply response of farmers to a rise in rice price is positive as expected but is low and inelastic. A one percent increase in rice price will increase its supply by 0.27 percent. A positive but inelastic response of output supply (rice or wheat) to its price has been common in Asia since 1970s. For example, supply response of Basmati rice in Pakistan Punjab is estimated at 0.27 (Farooq *et al.*, 2001), rice in Northern Thailand at 0.45 (Rahman and Sriboonchitta, 1995), and Mexican wheat in Indian Punjab at 0.63 (Sidhu and Baanante, 1981). On the other hand, a rise in rice price will result in a significant increase in demand for all inputs, the highest effect being on labour demand. A one percent increase in rice price will increase labour demand by 0.94% and pesticide demand by 0.53%, respectively.

All own price elasticities are negative, consistent with theory although they lie in the inelastic range. Price elasticity of demand for major inputs are closely similar ranging from -0.57 to -0.59 except fertilizers which is -0.25. A one percent reduction in input prices will increase its use by 0.57 to 0.59 percent (0.25 percent for fertilizer input).

[INSERT TABLE 3 HERE]

Among the fixed factor endowments, supply response to an expansion in land area is high, as expected. A one percent increase in land area will increase rice supply by 0.86 percent which is comparable to those obtained by Farooq et al., (2001), Rahman and Sriboonchitta (1995) and Sidhu and Baanante (1981). Among the inputs, response to an expansion in land area is also high. A one percent increase in land area under modern rice varieties will increase fertilizer demand by 0.92 percent and pesticide demand by 0.41 percent thereby reinforcing the chemical intensity argument of this GR technology. Irrigation and farm capital assets do not have significant influence on output supply and input demand.

Table 3 also shows the influence of soil fertility on both output supply and input demand in this cropping system. SOC is a commonly accepted indicator of soil fertility, there being a positive relationship between organic carbon content and productivity in most cropping systems (Parkinson, 2003). In this case, the influence of SOC is significantly positive on output (rice) supply. This confirms that for these rice farmers, high inherent soil fertility leads to greater yields. In addition, the analysis shows that farmers recognize that those soils with higher SOC, and hence greater nutrient exchange capacities, were more fertile, and exploited the greater ability of the soil to retain and supply fertilizer nutrients to the rice crop. These findings agree with the findings of Payton et al. (2003), who noted that farmers can distinguish “soil fertility” based on feel and visual observations, even in the absence of analytical data. The significant negative influence of SOC on input demand shows that the higher inherent fertility (and hence higher yielding) production systems required significantly less amount of inputs.

An increase in available N, P and K significantly increases rice supply, confirming well known relationships between soil fertility and crop productivity (Yadav, 2003), although the magnitude of influence is much higher for available K. Input demand declines significantly with increase in available P and N, the magnitude of influence being much higher for available P. In contrast, available K has significant positive influence on demand for all inputs. This observation is counterintuitive, and needs further investigation.

4. DISCUSSION AND POLICY IMPLICATIONS

The inclusion of "state-of-nature" variables in economic analysis of farmers' resource allocation decision is uncommon, although in reality farmers' production performance is highly likely to be influenced by both economic as well as bio-physico-chemical factors. The present study attempted to integrate these two strands of scientific enquiry into farmers' decision making processes. Therefore, we incorporated four key "state-of-nature" 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, irrigation and farm capital assets).

On the whole, changes in market prices of inputs and outputs significantly influenced farmers' resource use and productivity (rice supply) as expected. A rise in rice price will increase its supply as well as demand for all four inputs, with particularly high impact on labour use. Since modern rice production technology utilises higher share of hired labour, the rise in labour demand in response to rice price increase will lead to redistribution of gain accrued from modern technology to landless labourers via wages, an argument in favour of widespread GR technology diffusion in the first place. With respect to variable inputs, increases in their prices will depress rice supply, although the magnitude of responsiveness is in the inelastic range. The responsiveness to fertilizer price is lowest of all, implying that a rise in the price of fertilizer will have minimal depressing effect on rice supply. This is perhaps because farmers growing modern varieties of rice realises that fertilizer must be applied in order to obtain any decent amount of rice output irrespective of its relative cost. Low elasticity of fertilizer input is one of the principle reasons behind abolition of fertilizer subsidy and liberalisation of the fertilizer market in Bangladesh in 1992.

Among the conventional fixed factors, the role of paddy area in influencing productivity and resource use is a dominant factor. 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 rice 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 modern technology adoption via higher demand for hired labour owing to increase in paddy area. However, the influence of irrigation and farm capital asset on rice supply and input demand is quite limited. This is probably because 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. Similarly, farm capital assets possessed by most farmers are similar and largely composed of traditional equipment and tools with little variation in value and quality.

All of the soil fertility variables had significant influence on rice output as expected, thereby pointing towards their importance in raising farm productivity. The data analysis showed that output increases significantly with higher concentration of SOC and available soil N, P and K. Furthermore, there was a significant reduction in use of inputs in response to higher concentrations of SOC and available soil P and N. The results presented in this paper demonstrate that the disaggregation of soil fertility variables allows direct evaluation of the contribution that individual components of soil fertility can make to rice yield. This observation emphasises the importance of developing regional agricultural policy approaches that allow the transfer of indigenous knowledge, as farmers do not carry out either detailed nutrient budgets or soil nutrient analysis on a routine basis.

The overarching policy implication of this study is that enhancement of soil fertility exerts a dual impact on the production process, leading to an increase in crop yield, and the reduced use of variable inputs, thereby raising farmers' income and competitiveness in the market. Enhancement of soil fertility status through more efficient nutrient utilisation will be beneficial on both economic and bio-physico-chemical grounds. 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. The farmers surveyed here, operating on a range of soils of contrasting fertility status, were able to adjust input use effectively based on soil observation and indigenous knowledge (Payton et al., 2003). However, there are other agro-ecological zones in Bangladesh where lower natural soil fertility and lack of understanding of soil fertility limits crop production severely. In these situations, the transfer of inherent soil fertility knowledge acquisition skills is a necessary prerequisite for raising farm productivity in these less fertile areas, and will result in a more efficient utilisation of nutrients, while maintaining a relatively lower cost of input use. It is recommended that knowledge transfer of agro-economic advice at village level, emphasising soil nutrient budgeting, be implemented in order to allow increased nutrient utilisation efficiency in regions where soil fertility is depleted.

5. CONCLUSIONS

This research has demonstrated a clear relationship between soil fertility (a combined bio-physico-chemical factor) and farmers' resource allocation decisions (an economic factor) in rice production in the Jamalpur, Jessore and Comilla districts of Bangladesh. Results revealed that soil fertility has a significant influence on farmers' resource allocation decisions. In this area of Bangladesh, the supply of rice is significantly higher in fertile regions, as expected. We have shown that there is a close relationship between rice yield and disaggregated indicators of soil fertility. Our observation that the use of inputs is lower in more fertile regions reinforces the need for a regular soil evaluation and analysis programme to inform resource allocation decisions and hence increase competitiveness of these rice farmers by lowering the cost of inputs when soil fertility status is enhanced. Challenges remain, as the transfer of technological and intuitive knowledge is restricted by the lack of routine soil and crop monitoring procedures at farm level. There is a requirement to focus agronomic advice and support at the local level, and hence facilitate the transfer of indigenous knowledge from farmers in higher productivity areas.

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Table 1. Description, measure and summary statistics of the variables

Name	Description	Measurement	Mean	Standard deviation
PR	Profit from modern rice production	Taka[a]	10203.74	12345.33
Y	Quantity of modern rice output	Kg	2974.51	3153.39
X_F	Quantity of fertilizers	Kg	178.94	197.47
X_W	Quantity of labour	Person-days	63.11	57.21
X_M	Quantity of animal power services	Animal pair-days	19.40	20.97
X_P	Quantity of pesticides	100 g or ml of active ingredients	2.74	3.91
Y_R	Rice price	Taka kg^{-1}	5.64	0.44
F	Fertilizer price	Taka kg^{-1}	6.51	1.18
W	Labour wage	Taka person-day^{-1}	45.56	8.25
M	Animal power price	Taka pair-day^{-1}	84.71	17.72
P	Pesticide price	Taka per 100 g or ml of active ingredients	83.58	15.55
L	Land cultivated under modern varieties of rice	Hectare	0.73	0.79
G	Irrigation	Taka	1655.16	2471.83
C	Farm capital asset	Taka	12154.99	17183.39
O	Soil organic carbon	kg ha^{-1}	40.28	31.34
H	Available soil phosphorus	kg ha^{-1}	44.63	15.22
K	Available soil potassium	kg ha^{-1}	68.58	31.63

Q	Available soil nitrogen	kg ha^{-1}	38.11	11.98

Note: [a] = Exchange rate of USD 1.00 = Taka 42.70 in 1996 (BBS, 2001)

Table 2. Restricted parameter estimates of the translog profit function and factor share equations

Variables	Parameters	Coefficients	t-ratio
Profit Function			
Constant	α_0	-325.8535	-0.97
lnP'_F	α_F	-0.3255	-1.73*
lnP'_W	α_W	-1.3284	-2.59***
lnP'_M	α_M	-0.5583	-2.36**
lnP'_P	α_P	-0.1085	-0.56
½(lnP'_F x lnP'_F)	γ_{FF}	-0.1681	-9.37***
½(lnP'_W x lnP'_W)	γ_{WW}	-0.4619	-8.23***
½(lnP'_M x lnP'_M)	γ_{MM}	-0.1023	-5.45***
½(lnP'_P x lnP'_P)	γ_{PP}	-0.0453	-2.68***
lnP'_F x lnP'_W	γ_{FW}	-0.0309	-1.48
lnP'_F x lnP'_M	γ_{FM}	-0.0045	-0.35
lnP'_F x lnP'_P	γ_{FP}	-0.0369	-2.95***
lnP'_W x lnP'_M	γ_{WM}	-0.1205	-4.84***
lnP'_W x lnP'_P	γ_{WP}	-0.0326	-1.47
lnP'_M x lnP'_P	γ_{MP}	-0.0012	-0.10
lnP'_F x lnZ_L	δ_{FL}	0.0013	0.23
lnP'_F x lnZ_G	δ_{FG}	0.0028	1.10
lnP'_F x lnZ_C	δ_{FC}	0.0059	2.06**

Variables	Parameters	Coefficients	t-ratio
$lnP'_F \times lnZ_H$	δ_{FH}	0.0623	2.44**
$lnP'_F \times lnZ_O$	δ_{FO}	0.0307	3.04***
$lnP'_F \times lnZ_K$	δ_{FK}	0.0258	-1.57
$lnP'_F \times lnZ_Q$	δ_{FQ}	-0.0381	-2.02**
$lnP'_W \times lnZ_L$	δ_{WL}	0.0451	2.84***
$lnP'_W \times lnZ_G$	δ_{WG}	0.0280	3.99***
$lnP'_W \times lnZ_C$	δ_{WC}	0.0269	3.39***
$lnP'_W \times lnZ_H$	δ_{WH}	0.2918	4.24***
$lnP'_W \times lnZ_O$	δ_{WO}	0.1704	6.23***
$lnP'_W \times lnZ_K$	δ_{WK}	0.1089	2.42**
$lnP'_W \times lnZ_Q$	δ_{WQ}	-0.0559	-1.09
$lnP'_M \times lnZ_L$	δ_{ML}	-0.0037	-0.51
$lnP'_M \times lnZ_G$	δ_{MG}	0.0125	3.85***
$lnP'_M \times lnZ_C$	δ_{MC}	0.0119	3.25***
$lnP'_M \times lnZ_H$	δ_{MH}	0.1126	3.51***
$lnP'_M \times lnZ_O$	δ_{MO}	0.0661	5.15***
$lnP'_M \times lnZ_K$	δ_{MK}	0.0246	1.18
$lnP'_M \times lnZ_Q$	δ_{MQ}	-0.1012	-0.42
$lnP'_P \times lnZ_L$	δ_{PL}	0.0475	7.94***
$lnP'_P \times lnZ_G$	δ_{PG}	0.0042	1.62
$lnP'_P \times lnZ_C$	δ_{PC}	0.0031	1.05

Variables	**Parameters**	**Coefficients**	**t-ratio**
$lnP'_P \times lnZ_H$	δ_{PH}	0.0567	2.20**
$lnP'_P \times lnZ_O$	δ_{PO}	0.0349	3.38***
$lnP'_P \times lnZ_K$	δ_{PK}	0.0121	0.72
$lnP'_P \times lnZ_Q$	δ_{PQ}	-0..0468	-2.45**
lnZ_L	β_L	1.8342	2.72***
lnZ_G	β_G	-0.8041	-1.63
lnZ_C	β_C	0.0362	0.12
lnZ_H	β_H	12.0543	0.85
lnZ_O	β_O	-15.0747	-0.84
lnZ_K	β_K	71.1015	0.90
lnZ_Q	β_Q	125.9763	1.05
$\frac{1}{2}(lnZ_L \times lnZ_L)$	θ_{LL}	-0.1670	-0.66
$\frac{1}{2}(lnZ_G \times lnZ_G)$	θ_{GG}	0.0205	2.51***
$\frac{1}{2}(lnZ_C \times lnZ_C)$	θ_{CC}	0.0065	0.71
$\frac{1}{2}(lnZ_H \times lnZ_H)$	θ_{HH}	10.7665	0.94
$\frac{1}{2}(lnZ_O \times lnZ_O)$	θ_{OO}	-6.7892	-1.09
$\frac{1}{2}(lnZ_K \times lnZ_K)$	θ_{KK}	3.0320	0.87
$\frac{1}{2}(lnZ_Q \times lnZ_Q)$	θ_{QQ}	-16.4661	-1.08
$lnZ_L \times lnZ_G$	θ_{LG}	-0.1459	-1.52
$lnZ_L \times lnZ_C$	θ_{LC}	-0.0223	-2.35**
$lnZ_L \times lnZ_H$	θ_{LH}	-0.1638	-1.74*

Variables	Parameters	Coefficients	t-ratio
lnZ_L x lnZ_O	θ_{LO}	0.0087	0.25
lnZ_L x lnZ_K	θ_{LK}	0.0186	0.28
lnZ_L x lnZ_Q	θ_{LQ}	-0.0952	-1.41
lnZ_G x lnZ_C	θ_{GC}	0.0027	0.81
lnZ_G x lnZ_H	θ_{GH}	0.0763	1.21
lnZ_G x lnZ_O	θ_{GO}	-0.0024	-0.09
lnZ_G x lnZ_K	θ_{GK}	0.0219	0.37
lnZ_G x lnZ_Q	θ_{GQ}	0.0730	1.61
lnZ_C x lnZ_H	θ_{CH}	-0.0169	-0.41
lnZ_C x lnZ_E	θ_{CE}	-0.0172	-1.15
lnZ_C x lnZ_K	θ_{CK}	-0.0347	-1.18
lnZ_C x lnZ_Q	θ_{CQ}	0.0230	0.77
lnZ_H x lnZ_O	θ_{HO}	6.4610	0.96
lnZ_H x lnZ_K	θ_{HK}	-8.1742	-0.83
lnZ_H x lnZ_Q	θ_{HQ}	-10.0507	-1.08
lnZ_O x lnZ_K	θ_{QK}	-1.7217	-0.73
lnZ_O x lnZ_Q	θ_{OQ}	5.6452	0.99
lnZ_K x lnZ_Q	θ_{KQ}	-12.1497	-0.97
Fertilizer share equation			
Constant	α_F	-0.3255	-1.73*
lnP'_F	γ_{FF}	-0.1681	-9.37***

Variables	**Parameters**	**Coefficients**	**t-ratio**
lnP'_W	γ_{FW}	-0.0309	-1.48
lnP'_M	γ_{FM}	-0.0045	-0.35
lnP'_P	γ_{FP}	-0.0369	-2.95***
lnZ_L	δ_{FL}	0.0013	0.23
lnZ_G	δ_{FG}	0.0028	1.10
lnZ_C	δ_{FC}	0.0060	2.06**
lnZ_H	δ_{FH}	0.0623	2.44**
lnZ_O	δ_{FO}	0.0307	3.04***
lnZ_K	δ_{FK}	0.0258	1.57
lnZ_Q	δ_{FQ}	-0.0381	-2.02**
Labor share equation			
Constant	α_W	-1.3284	-2.59***
lnP'_F	γ_{FW}	-0.0309	-1.48
lnP'_W	γ_{WW}	-0.4619	-8.23***
lnP'_M	γ_{WM}	-0.1215	-4.84***
lnP'_P	γ_{WP}	-0.0326	-1.47
lnZ_L	δ_{WL}	0.0451	2.84***
lnZ_G	δ_{WG}	0.0280	3.99***
lnZ_C	δ_{WC}	0.0269	3.39***
lnZ_H	δ_{WH}	0.2917	4.24***
lnZ_O	δ_{WO}	0.1704	6.23***

Variables	Parameters	Coefficients	t-ratio
lnZ_K	δ_{WK}	0.1089	2.42**
lnZ_Q	δ_{WQ}	-0.0559	-1.09
Animal share equation			
Constant	α_M	-0.5582	-2.36**
lnP'_F	γ_{FM}	-0.0045	-0.35
lnP'_W	γ_{WM}	-0.1205	-4.84***
lnP'_M	γ_{MM}	-0.1023	-5.45***
lnP'_P	γ_{MP}	-0.0012	-0.10
lnZ_L	δ_{ML}	-0.0037	-0.51
lnZ_G	δ_{MG}	0.0125	3.85***
lnZ_C	δ_{MC}	0..0119	3.25***
lnZ_H	δ_{MH}	0.1126	3.51***
lnZ_O	δ_{MO}	0.0661	5.15***
lnZ_K	δ_{MK}	0.0246	1.18
lnZ_Q	δ_{MQ}	-0.0101	-0.42
Pesticide share equation			
Constant	α_P	-0.1085	-0.56
lnP'_F	γ_{FP}	-0.0369	-2.95**
lnP'_W	γ_{WP}	-0.0326	-1.47
lnP'_M	γ_{MP}	-0.0012	-0.10
lnP'_P	γ_{PP}	-0.0453	-2.68***

Variables	**Parameters**	**Coefficients**	**t-ratio**
lnZ_L	δ_{PL}	0.0475	7.94***
lnZ_G	δ_{PG}	0.0042	1.62
lnZ_C	δ_{PC}	0.0031	1.05
lnZ_H	δ_{PH}	0.0567	2.20**
lnZ_O	δ_{PO}	0.0649	3.38***
lnZ_K	δ_{PK}	0.0121	0.72
lnZ_Q	δ_{PQ}	-0.0468	-2.45**
Log likelihood		1420.28	
Observations		380	

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

** Significant at 5 percent level ($p<0.05$)

* Significant at 10 percent 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, P = pesticide price, L = land cultivated, G = irrigation, C = farm capital asset, H = available soil phosphorus, O = soil organic carbon concentration, K = available soil potassium, and Q = available soil nitrogen.

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 3. Estimated elasticities of translog profit function

	Rice price	Fertilizer price	Labour wage	Animal power price	Pesticide price	Land	Irrigation	Farm capital asset	Available soil phosphorus	Available soil carbon	Available soil potassium	Available soil nitrogen
Rice supply	0.266	-0.011	-0.050	-0.065	-0.011	0.883	0.061	0.114	0.826	0.301	3.641	0.876
	(6.08)***	(-1.47)	(-2.18)**	(-3.73)***	(-1.35)	(16.87)***	(1.65)*	(0.50)	(2.51)***	(2.16)**	(2.90)***	(1.97)**
Fertilizer demand	0.164	-0.251	-0.159	-0.157	0.230	0.923	0.064	-0.011	-6.391	-0.714	3.523	-0.874
	(1.74)*	(-1.68)*	(-1.92)*	(-2.10)**	(1.73)*	(14.65)***	(1.60)	(-0.09)	(-2.55)***	(2.12)**	(2.83)***	(-2.03)**
Labour demand	0.944	-0.145	-0.571	0.324	0.063	0.739	-0.033	-0.077	-6.142	-0.590	3.628	-1.027
	(2.18)**	(-1.91)*	(-2.99)***	(1.07)	(0.53)	(12.95)***	(-0.06)	(-0.99)	(-2.50)***	-(1.77)*	(2.95)***	(-2.02)**
Animal power demand	0.463	-0.120	0.308	-0.580	-0.070	0.956	0.012	0.002	-6.248	-0.643	3.583	-0.962
	(3.73)***	(-2.10)**	(1.07)	(-7.17)***	(-1.38)	(15.99)***	(0.34)	(0.25)	(-2.52)***	(2.15)**	(2.87)***	(-2.00)**
Pesticide demand	0.534	0.261	-0.055	-0.182	-0.576	0.409	0.041	-0.259	-6.562	-0.798	3.452	-0.770
	(2.79)***	(0.72)	(-1.09)	(-1.51)	(-4.02)***	(5.75)***	(0.77)	(-1.79)*	(-2.54)***	-(2.12)**	(2.77)***	(-1.78)*

Note: Elasticity estimates computed at mean values.

Figures in parentheses are t-ratios.

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

** Significant at 5 percent level ($p<0.05$)

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