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Impact of urea price change on the economic optimum level of N fertilizer use in HYV rice and its yield in Bangladesh[1]

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ABSTRACT

The study estimates the impact of change in urea price on the economic optimum level of N fertilizer use in HYV rice and its yield in Bangladesh using a large set of experimental data of BRRIfrom 15 regions covering an 11 year period (2001–2011). Results revealed that the level of N fertilizer usedin experiments to increase HYV rice yield was far lower than the economic optimum level in Aman and Boro seasonsbut higher in Aus season. The discrepancy was highest for HYV Boro rice closely followed by HYV Aman rice. Simulation exercise revealed that an increase in real price of urea by 50% will exert a 4% reduction in optimum dose of N fertilizer in HYV Amanrice and reduce yield by 101.2 kg/ha which issubstantial. The corresponding effect on HYV Bororice is relatively lowerand negligible for HYV Aus rice. The result highlights the dilemma and the detrimental effect of urea price increase on the yield ofHYV Aman rice which is the main source of foodgrain supply for the nation. Therefore, price policy should be geared towards controlling relative price of urea which can be met by a combination of subsidizing urea price and/or improving rice price.

Key Words: Economic optimization,Nfertilizer, HYV rice yield, simulation, Bangladesh.

1. Introduction

Rice is the staple food of Bangladeshi diet and will remain as such in the foreseeable future despite area under other cereals, particularly wheat and maize, is rising gradually over time.Rice alone occupies 79.2% of gross cropped area (Rahman and Kazal, 2015). It is largely believed that the efforts in countrywide diffusionof a rice-based 'Green Revolution' (GR) technology since the beginning of the 1960s tofulfil the goal of foodgrain self-sufficiency have largely been paid off in recent years(Rahman, 2010).In fact, rice productivity has increased remarkably with Bangladesh topping the list in Asia. For example, productivity of rice increased from only 1.68 t/ha in 1961 to a high 4.36 t/ha in 2013, therebybeating Sri Lanka who enjoyed higheryield levels during the 1960s and 1970s (Table 1).

Nevertheless, productivity of rice in Bangladesh can be increased furtherby increasing adoption rate of the GR technology package in full, particularly by improving nutrient management. One of the main pillars of successful outcome of a rice-based GR technology is the use of inorganic fertilizers, particularly application of the three major nutrients (i.e., N, P and K fertilizers) to support plant growth and grain yield of the High Yielding Varieties (HYV) of rice.Ahmed (2001) noted that the level of total fertilizer use in Bangladesh is 40–70% below recommended level. There is a significant gap in the use of N, P, K fertilizers between the recommended and actual level for all three growing seasons of rice. The gap is more significant for phosphate and potassium fertilizers (estimated at 64.1–72.3% for TSP and 69.1–75.4% for MP) as compared to urea (estimated at 4.3–28.6% for urea) in Bangladesh (MoA, 2004 cited by Jaim and Akter, 2012). Mujeri*et al*. (2012) noted that the current pattern of fertilizer use with heavy reliance on nitrogenous fertilizer coupledwith poor nutrition managementand weakmarketing and distribution systems have emerged as major constraints in improving the effectivenessin fertilizer use in South Asia. They have also emphasized that due to lack of efficiency and effectiveness in fertilizer use, there is concern regarding sustainability of fertilizer use.

1.1 Fertilizer subsidy in Bangladesh

Since the introduction of the GR technology in the 1960s, the Government of Bangladesh (GoB) had undertaken a range of policies to facilitate widespread use of inorganic fertilizers by the farmer by controlling its prices, distribution and marketing systemwhich is summarised in Table 2. When fertilizer was first introduced in Bangladesh, it was heavily subsidized with monopolistic control by Bangladesh Agricultural Development Corporation

(BADC). Since then various measures were undertaken to simplify the procurement and distribution system of fertilizers while maintaining control by the government. It is only during the 1990s, when greater liberalization of the fertilizer sector was initiated which showed considerable success during its initial years. However, during the last decade, privatization of the fertilizer sector led to several episodes of crises, particularly for urea fertilizer. The government then reverted back to heavy level of subsidy in fertilizers from 2012, the outcome of which is not yet fully realized. Table 3 clearly shows that the level of fertilizer subsidy in Bangladesh has increased 60 times in a space of 12 years from only BDT 1.0 billion in 2001/02 to BDT 59.9 in 2012/13 in real terms (Mujeri et al., 2012 and MoA, 2014).

1.2 Impact of fertilizer subsidy

Literature on the impact of subsidy on inputs, particularly fertilizers, is mixed. For instance, Barker andHayami (1976) noted that subsidy of modern inputs (e.g., fertilizer) that was being used below optimum level can be more beneficial than supporting product prices. In contrast, Ahmed (1978) concluded that for any reduction in the budgetary burden of subsidy, the government should explore price support programme before reducing fertilizer subsidy. Bayes*etal*.(1985) concluded that some combination of price support and fertilizer subsidy is preferable to achieve rice self-sufficiency in Bangladesh. Renfro (1992) noted that the liberalization of fertilizer marketing and price policies in Bangladesh had led to an expanded role for the private sector and benefited farmers in reduced prices and timely supply of fertilizers. Zahir (2001) revealed that reduction of subsidy would reduce farmers' profit (net income) which could adversely affect crop sector growth. Begum and Manos (2005) also showed that a policy of increased price of fertilizer (i.e., reduction of subsidy) would have a huge impact on farm income and employment.

It is apparent that the agricultural input subsidy policies (i.e. diesel and fertilizers)were devised by GoBas a tool for allowing a 'level playing field' for the Bangladeshi farmers in a trade liberalized era, whereas farmers in India were receiving subsidies for several inputs, e.g., irrigation, electricity, etc. Islam *etal*. (2007) found that the farmers in general were using excessive urea and comparatively fewer amounts of TSP and MP, while converse is also found in some cases. Kafiluddin and Islam(2008) showed that the prices of TSP, DAP and MP increased abruptly in the international market during 2003/04 which has adversely affected balanced use of fertilizer. However, reintroduction of subsidy in phosphate and potassium fertilizers from 2005/06 improved fertilizer use and crop production increased significantly in the country.Barkat*etal*.(2010) suggested subsidy scheme targeted for small farmers as they have limited opportunities to cope with price changes. Jaim and Akter (2012) also noted that the liberalization of fertilizer market did not take into account effects on small and marginal farmers and resulted in inefficiencies, price hikes, fertilizer crises, overuse and adulteration. Mujeri*et al*. (2012) also noted adulteration of fertilizers in South Asia.

Given this backdrop of circular policy changes in fertilizer pricing, distribution and marketing system and mixed account of the impact of such policies at the farm level including unbalanced and gaps in fertilizer use, it is important to identify the impact of fertilizer price change on the economic optimum level of fertilizer use in rice and corresponding yield levels. Therefore, the specific objectives of this study are to: (1) determine the economic optimum level of nitrogen (N) fertilizer use in HYV rice for each of the three cropping seasons (i.e., Aus, Aman and Boro seasons); and (2) estimate the impact of urea price change on the economic optimum level of N fertilizer in HYV rice and its yield for all three seasons.

This task was undertaken by using a large dataset of fertilizer trials on HYV rice of three growing seasons of the Bangladesh Rice Research Institute (BRRI) covering an 11 year period (2001–2011). The advantages of using such dataset are as follows: (1) since these are experiments, scientists keep an accurate record of fertilizer doses; (2) plot size of experiments are uniform; (3) the assumption of *ceteris paribus*(i.e., all other things being equal) for all other inputs is maintained with variation in fertilizer doses only (which satisfy the main requirement of this study); (4) since these experiments were conducted on different varieties of HYV rice of three seasons at multiple testing sites of BRRI over time, we can control for variations in agroecology, production environment and time. Therefore, the main contributionsof our study to the existing literature are as follows: (1) it aims to provide an accurate account of economic optimum level of N fertilizer use in HYV rice cultivation for each of the three growing seasons while accounting for variation in varietal differences, agro-ecological and production conditions and time; and (2) it provides a scenario analysis of urea price change on the economic optimum level of N fertilizer use in HYV rice and its yield for all three seasons.

2. Methodology

2.1 Analytical framework

The main objective of this study is to determine the economic optimum level of N fertilizer use in HYV rice and its yield for all three growing seasons. The basic modelling framework is as follows:

Let Y be the yield of rice per ha and X be the fertilizer use rate per ha. Assuming all other inputs being equal, then the quadratic yield response function can be fitted as:

$$Y = \alpha + \beta X + \gamma X^2 + \varepsilon \qquad (1)$$

where α, β, and γ are the parameters to be estimated, and ε is the error term.

The first order condition yields:

$$\frac{dy}{dx} = \beta + 2\gamma X = 0 \qquad (2)$$

Solving this first order condition, i.e., Eq (2) for X provides the yield maximizing level of X fertilizer use only, but not the economic optimum. However, equating this first order condition to the price ratio of fertilizer to rice (*Px/Py*) and solving for X provides the economic optimum level of fertilizer use which also maximizes yield, all other things being equal. This is because, by doing so, the solution equates the marginal product of X with the marginal cost of producing X, which is the condition for economic optimization under the assumption of perfect competition. The solution of optimum level of fertilizer (X*) is given by:

$$\frac{dy}{dx} = \beta + 2\gamma X = Px / Py \qquad (3)$$

$$X^* = \frac{Px / Py - \beta}{2\gamma} \qquad (4)$$

2.2 The empirical model

The model described in section 2.1 requires that except N fertilizer, all other inputs should remain constant. But the experimental data we received has variations in the dose of nitrogen as well as potassium and phosphate fertilizers. Therefore, we need to keep the framework but extend the model to accommodate variation in doses of potassium and phosphate fertilizers. Also, such extension provides a more realistic estimation of yield response of rice to Nfertilizer while controlling for the use of other two main fertilizers, P and K. The extended quadratic model of the yield response function is given by:

$$Y = \alpha + \sum_{i=1}^{3} \beta_k X_i + \sum_{i=1}^{3}\sum_{k=1}^{3} \gamma_{ik} X_i X_k + \sum_{t=1}^{11}\sum_{l=1}^{15} \delta_{tl} T_t L_l + \varepsilon \qquad (5)$$

where Y is the yield of rice, X is the active ingredient of fertilizer nutrients (i = 1, 2 and 3 where 1 = N (nitrogen), 2 = P (phosphorus) and 3 = K (potassium); T is the set of dummy variables to account for years (t = 2001 … 2011); L is the set of dummy variables to account for locationsof the experiments (l = 1, ….. 15) ; α, β, γ, and δ are the parameters to be estimated, and ε is the error term.

The first order condition with respect to N provides:

$$\frac{dy}{dX_1} = \beta_1 + \gamma_{11} 2X_i + \gamma_{12} X_2 + \gamma_{13} X_3 = 0 \qquad (6)$$

Equating this first order condition to the real price ratio of fertilizer to rice (*Px_1/Py*) and solving for X_1 provides the economic optimum level of N fertilizer use, all other things being equal. The solution of economic optimum N fertilizer (X_1*) is given by:

$$\frac{dy}{dX_1} = \beta_1 + 2\gamma_{11} X_i + \gamma_{12} X_2 + \gamma_{13} X_3 = Px_1 / Py \qquad (7)$$

$$X_1^* = \frac{Px_1 / Py}{2\gamma_{11}} - \frac{1}{2\gamma_{11}} (\beta_1 + \gamma_{12} X_2 + \gamma_{13} X_3) \qquad (8)$$

First, we need to estimate Eq (7) to derive the economic optimum dose of N fertilizer on yields of HYV Aman, HYV Boro and HYV Aus, respectively. Next, using the optimum dose of N fertilizer as shown inEq (8), we simulate or explore two sets of questions: (a) what is the effect of real price changes of urea on the optimum level of N fertilizer use, keeping real price of rice constant; and (b) what is the effect of real price changes of urea on HYV rice yield. To obtain simulation results of change in optimum dose of N fertilizer in response to price change, we use Eq (8) by changing price ratios as required. To obtain an estimate of the effect on HYV rice yield (Y) due to change in optimum dose of N fertilizer in response to change in real price of urea fertilizer, we use the following formula:

$$\Delta Y = \beta_1 (X_1^f - X_1^i) + \gamma_{11} [(X_1^f)^2 - (X_1^i)^2] + \gamma_{12} (X_1^f - X_1^i) \bar{X}_2 + \gamma_{13} (X_1^f - X_1^i) \bar{X}_3 \qquad (9)$$

where X_1^i (the initial level before prices increased) and X_1^f (the final level after prices increased); the regression coefficients come from Eq. (7), and $\bar{X}_2$ and $\bar{X}_3$ represent the mean levels of the use of P and K fertilizers, respectively. All models were estimated by using the econometric software STATA Version 10 (StataCorp, 2007).

2.3 Data and the variables

The BRRI experimental data on various HYV rice of Aus, Aman and Boro seasons were taken for a period of 11 years, i.e., 2001–2011. These experiments were conducted in various research stations of BRRI located in 15 regions, hence include wide variations in production environment and agroecology. Data include yield per hectare (kg) and corresponding doses of N, P and K fertilizers (BRRI annual reports, various issues). The price data of rice by season (Aus, Aman and Boro) and urea fertilizers for each corresponding year was taken from various issues of Bangladesh Statistical Yearbooks (BBS, various issues). The nominal price data were then converted into real price with 2011 as the base year. This exercise takes out the effect of inflation from the price data which is important in a nation like Bangladesh where inflation rate is very high. The final sample size stands at 887 HYV Aman rice, 919 HYV Boro rice, and 72 HYV Aus rice. The paucity of sample size of HYV Aus rice demonstrates the focus of research on the main two seasons of rice only, i.e., HYV Aman and HYV Boro rice by BRRI.

3. Results

Table A1 in the appendix presents the results of the parameter estimates of Eq (7) for HYV Aman, HYV Boro and HYV Aus models. All the regressions have good explanatory power. The F-statistic confirms that the use of these sets of variables significantly explains variation in the level of HYV rice yield. The adjusted R^2 valuesare estimated at 0.31 for HYV Aman rice, 0.40 for HYV Boro rice and 0.60 for HYV Aus rice, respectively. A number of location-time dummy interaction variables are significantly different from zero, which justifies the need to control for locational and temporal variation in rice production. For example, the coefficient on the Gazipur2001 for HYV Aman rice is 1287.4 indicating that the average yield per hectare in Gazipur area in 2001 is 1287.4 kg higher than the mean yield of the total sample.

Table 4 presents the levels of N, P andK fertilizers used in the experiment stations to maximize HYV rice yield. The study also reports the estimated economic optimum level of N fertilizer (X_1*) along with standard deviation. The table also reports a set of simulated response of optimum level of N fertilizer as the real price of urea changes, keeping real rice price constant. It present changes in optimum level of N fertilizer use in response to 10%, 20%, 30%, 40% and 50% increase in the real price of urea fertilizer. Finally, the last five rows show the effect of the changes in optimum level of N fertilizer on HYV rice yield.

It is clear from Table 4 that the economic optimum of N fertilizer use is much higher than the level of fertilizer used in experiments except for Aus rice where it is lower. For HYV Aman rice, the optimum level of N is 120.9 kg/ha whereas the use level in experiments is only 75.4 kg/ha along with 40.7 kg/ha of P and 11.18 kg/ha of K. In other words, the economic optimum level of urea fertilizer use is 60% higher than used in the experiments, implying that an additional 45.4 kg/ha is needed to maximize HYV Aman rice yield which is also economically optimum. Similarly, for HYV Boro rice, the optimum level of N fertilizer use is 67.2% higher than the dose used in the experiments, implying that an additional 83.9 kg/ha of N is required. The scenario is exactly opposite with the case of HYV Aus rice. It should be noted that the number of observations in Aus rice is too small (only 72), therefore, the results should be treated with caution. The optimum dose of N fertilizer is estimated at 58.1 kg/ha whereas the level used in the experiment station is much higher at 66.1 kg/ha implying that experiment stations are overusing N fertilizer in Aus rice and one can reduce urea fertilizer by 8.0 kg/ha.

Table 4 also shows that changes in real price of urea have notable reduction in optimum dose of N fertilizer for Aman rice only and minor effect on Boro and Aus rice. In case of Aman rice, a 50% rise in the price of urea will reduce optimum level of N fertilizer by 4.6 kg/ha or 3.8% reduction. This needs attention because Aman season provides the bulk of rice output of the country and movements in the price of urea fertilizer will have discernible effect on its optimum usage.

Finally, the study presents the effect on yield of HYV rice due to change in optimum doses of N fertilizer in response to movements in the price of urea fertilizer. The results show large scale reduction in the yield of Aman rice followed by moderate reduction on Boro rice but no effect on Aus rice. A 50% increase in the real price of urea will reduce HYV Aman rice yield by 101.7 kg/ha followed by Boro rice yield by 24.9 kg/ha. Once again, the rise in the urea price will exert detrimental effect on Aman rice crop, which is a matter of concern.

4. Conclusions and policy implications

The main objective of this study is to estimate the impact of urea price changes on the economic optimum level of N fertilizer use in HYV rice production and its yield for Aus, Aman and Boro seasons, respectively.The results revealed that the experimental level of N fertilizer use is far lower than the economically optimum level of N fertilizer for Aman and Boro seasons but higher for Aus season. The gap is highest for HYV Boro rice closely followed by Aman rice. An increase in real price of urea by 50% will exert a 3.8% reduction in optimum dose of N fertilizer in HYV rice cultivation inAman season and reduce rice yield substantially by 101.2 kg from its existing level, which is a serious detrimental effect. The corresponding effect on HYV Bororice is not so high but should not be ignored either. The effect of price change of N fertilizer on HYV Aus rice is negligible.

The present analysis demonstrates the detrimental effect of a reduction in fertilizer subsidy that will be exerted on the yield level of principal rice crop, i.e., HYV Aman rice, which provides the bulk of foodgrain supply for the nation. Therefore, price policy should be aimed at controlling real and/or relative price of urea with respect to rice price. This can be achieved by either continuing to subsidize urea fertilizer or by increasing rice price or a combination of both.Mujeri*et al*. (2012) also concluded that subsidy on fertilizers needs to continue in Bangladesh in order to make crop production attractive and profitable.

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Table 1. Productivity of rice (mt/ha) in Asia (1961–2013).

Country	1961	1971	1981	1991	2001	2013
Bangladesh	1.68	1.58	1.94	2.59	3.31	4.36
Bhutan	1.44	1.44	1.46	1.25	1.44	2.94
India	0.95	1.14	1.40	1.93	2.42	2.96
Nepal	1.85	1.72	1.70	1.85	2.18	2.57
Pakistan	0.86	1.20	1.67	1.81	2.23	2.72
Sri Lanka	1.77	1.94	2.55	2.93	3.42	3.83
Asia	1.21	1.67	2.15	2.83	3.17	3.94

Note: Compiled from World Agriculture Statistics database (FAOSTAT, various issues).

Table 2. Key policy changes in fertilizer pricing, distribution and marketing system in Bangladesh.

Period	Policy	Main actor	Procurement	Distribution	Outcome
1950 – 1976	High level of subsidy (upto 52% during 1975/76); Sale price fixed by GoB	BADC	BADC alone responsible for procurement from domestic producers, donor-supplies and imports	BADC appointed dealers to collect fertilizer from BADC distribution points and deliver to farmers at fixed prices	Time consuming; Erratic supply at times of need, BADC has limited transportation and storage capacity, low commission to dealers acted as deterrent
1977 – 1987	New Marketing System supported initially by USAID project in 1977/78; Retail price deregulation; Substantial reduction of subsidy to only 4% in 1982/83	BADC; Private sector dealers	BADC alone responsible for procurement from domestic producers, donor-supplies and imports	BADC appointed dealers to collect fertilizer from more primary distribution points and sell it to farmers at competitive prices	Increased farmer's access to fertilizer sources; Lowered/deregulated retail prices; Consolidated government warehousing; Produced a minimal effect on the government's distribution costs; Lifting of fertilizer by dealers were still time-consuming
1987 – 1989	New Marketing System continuing; Subsidy is still maintained by reduction in fertilizer prices under command area of dealers	IFDC through MoA	Dealers to procure from port and factories directly	Private dealers to sell to farmers at market prices	Lower farm level prices of fertilizers
1990 – 1994	Privatization of the fertilizer market; Subsidy of fertilizers partially removed (remained for urea)	Dealers and private companies	Dealers and private companies are free to import all types of fertilizers	Private sector responsible for all types of distribution and sale at market prices	Significant economies of scale achieved; substantial reduction in real farm level prices; fertilizer use increased at an average rate of 8.5% per year; Bangladesh received self-sufficiency in rice production in 1993/94; Bangladesh Fertilizer Association created in 1993;

Period	Policy	Main actor	Procurement	Distribution	Outcome
1995 – 2008	Reintroduction of subsidies upto 25% for phosphate and potassium fertilizers due to hike in world prices during 2003/04; New Dealership Policy in 2008 to appoint one dealer for each union	Judicial commission appointing district level dealers;	Dealers and private companies are free to import all types of fertilizers	Private sector responsible for all types of distribution and sale at market prices	Several fertilizer crises during this privatization period of Open Market Sale policy; weak policy failed to implement effectively
2009 – 2011	Subsidy on fertilizers maintained; New Dealership Policy 2009 introduced; Open market sale re-introduced	BCIC; Abolition of sales representative of dealers, restriction of dealership within the district; use of ID card for dealers	BCIC controlling production and import of urea	BADC and private sector responsible for all types of distribution and sale at market prices	Several episodes of urea fertilizer crises in 2007, 2008 and 2009
2012 –	Heavy subsidy on fertilizers continued	BCIC; BADC	BCIC controlling production and import of urea	BADC and private sector responsible for all types of distribution and sale at market prices;	Drastic reduction of TSP, MP and DAP prices through subsidy
2013 –	National Agricultural Policy 2013 launched	GoB and Private sector; GoB to monitor the fertilizer sector	GoB and private sector can purchase and procure fertilizers; GoB will ensure storage at regional, district and upazila level for emergencies	GoB and private sector to distribute and sell to farmers	No specific outcome available

Source: Compiled from Mujeri et al. (2012); Barkat et al. (2010); Jaim and Akter (2012); MoA(2013).

Table 3. Fertilizer subsidy in Bangladesh

Year	Total amount (in billion Taka at current prices)	Total amount (in billion Taka at constant prices)
2001-02	1.0	1.0
2002-03	2.0	1.9
2003-04	3.0	2.7
2004-05	6.0	5.1
2005-06	12.0	9.5
2006-07	15.4	11.4
2007-08	22.5	15.1
2008-09	57.9	36.5
2009-10	49.5	29.1
2010-11	55.21	30.7
2011-12	69.93	36.8
2012-13	119.93	59.9

Source: Compiled from Mujeri et al. (2012) and MoA (2014).

Table 4: Simulation results of the economic optimum levels of N fertilizer use and effect on HYV rice yield in response to urea price change

Variables	HYV Aman model		HYV Boro model		HYV Aus model	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Experimental P (TSP)	11.18	2.18	20.71	6.04	13.43	5.05
Experimental K (MP)	40.71	6.56	51.88	12.31	44.93	10.60
Experimental N (Urea)	75.42	17.79	125.71	16.97	66.08	20.76
Optimum N	120.86	79.07	209.58	18.11	58.08	13.77
Optimum N (10% rise in urea price)	119.94	79.06	209.38	18.10	58.13	13.77
Optimum N (20% rise in urea price)	119.02	79.06	209.17	18.10	58.17	13.77
Optimum N (30% rise in urea price)	118.10	79.05	208.97	18.10	58.22	13.78
Optimum N (40% rise in urea price)	117.19	79.06	208.76	18.10	58.27	13.77
Optimum N (50% rise in urea price)	116.27	79.05	208.56	18.10	58.32	13.77
Yield effect (10% rise in urea price)	-19.74	22.13	-4.97	4.46	0.04	0.01
Yield effect (20% rise in urea price)	-39.78	44.29	-9.95	8.92	0.09	0.03
Yield effect (30% rise in urea price)	-60.13	66.46	-14.93	13.38	0.15	0.04
Yield effect (40% rise in urea price)	-80.77	88.66	-19.91	17.85	0.20	0.06
Yield effect (50% rise in urea price)	-101.72	110.87	-24.90	22.31	0.26	0.07

Appendix Table A1: Yield response function of HYV rice using BRRI experimental data (2001-2011)

Variables	HYV Aman model		HYV Boro model		HYV Aus model	
	Coefficient	**t-ratio**	**Coefficient**	**t-ratio**	**Coefficient**	**t-ratio**
Constant	656.7418	0.69	5688.2540***	4.91	4199.0780	0.21
N	51.0808***	3.39	-23.7173	-1.50	34.9487	0.05
P	-73.1019*	-1.69	-181.8295	-1.42	0.0000	0.00
K	9.7920	0.56	12.3207	0.53	0.0000	0.00
N*N	-0.1743***	-3.05	-0.0449	-0.82	0.9232	1.06
P*P	-0.6897	-0.9	-3.2253	-1.08	15.5786*	1.65
K*K	0.0303	0.22	0.0003	0	1.4079	0.14
N*P	1.0502***	3.30	3.2709***	3.82	-5.8670	-0.79
N*K	0.0182	0.14	-0.0289	-0.16	-1.3915	-0.08
P*K	-0.8032*	-1.75	-0.3560	-0.21	-6.8435	-0.37
Time-location dummy variables						
Gazipur2001	1287.4030***	3.56	-356.2755	-0.83	-103.3333	-0.1
Gazipur2002	1764.1950***	4.74	-546.9726	-1.01	-500.0000	-0.47
Gazipur2003	1040.9130**	2.14	18.9784	0.05		
Gazipur2004			-837.9062**	-2.14		
Gazipur2005	1287.0570***	3.13	-278.9436	-0.84	230.0000	0.29
Gazipur2006	514.1336	1.55	-936.1234***	-3.22	-370.0000	-0.46
Gazipur2007	864.1081**	1.99	-455.6468	-1.51		
Gazipur2008	490.9231	1.36	-568.3145*	-1.80	930.0000	0.82
Gazipur2009	610.3704*	1.65	-806.8659**	-2.35		
Gazipur2010	107.0118	0.31	-822.8898***	-2.66	975.0000*	1.64
Gazipur2011	991.8527***	2.66	-394.4944	-1.18	469.4950	0.45
Comilla2001	2456.0510**	2.54	-1287.4100***	-2.68		
Comilla2002			462.5902	0.75		
Comilla2003	1935.7670***	4.23	-143.7468	-0.27		
Comilla2004	1946.6860***	3.17				
Comilla2005	1664.1860***	3.00				
Comilla2006	397.4484	0.93	-724.1204**	-2.17	-120.0000	-0.15
Comilla2007	526.0505	0.55	312.5902	0.50		
Comilla2008	1139.8880***	2.69	-378.4998	-0.78		
Comilla2009	271.7250	0.61	-595.9151	-1.23		
Comilla2010	1377.2470	1.43	150.7361	0.40		
Comilla2011	1882.1530***	3.63	-567.7628	-1.18		
Habiganj2003	1144.8950	1.59				
Habiganj2006	660.8789	1.19	-348.9117	-0.66		
Habiganj2007	722.9625*	1.71	-187.4098	-0.3		
Habiganj2008	1704.5780***	3.62	412.5902	0.5		
Habiganj2009	1934.8520***	4.89				
Habiganj2010	1500.1130**	3.28	468.8197	0.75		
Habiganj2011	3234.1530***	6.23				
Kushtia2001			-651.0569	-1.22	-199.6212	-0.19
Kushtia2003			552.5902	0.66		
Kushtia2006	1499.6750***	3.35	535.7795	1.11		
Kushtia2008	550.9361	1.12	-927.9656**	-2.36	-746.7424	-0.66
Kushtia2009			-1177.8800**	-1.96	-1020.0000	-1.26
Kushtia2010	-0.4495	0	24.6196	0.05		

Variables	HYV Aman model		HYV Boro model		HYV Aus model	
	Coefficient	t-ratio	Coefficient	t-ratio	Coefficient	t-ratio
Kushtia2011	1823.3790**	2.54	45.9235	0.09		
Rajshahi2002			-287.4098	-0.46		
Rajshahi2003			-1201.5540***	-2.95		
Rajshahi2006	430.3131	0.77	231.2007	0.74	-1243.3330*	-1.89
Rajshahi2007	2453.5060***	5.66	886.7385	1.41		
Rajshahi2008	492.2472	0.88	-843.4998	-1.36		
Rajshahi2009					-12.3409	-0.01
Rajshahi2010	422.7306	1.01	53.8197	0.09		
Rajshahi2011	701.8563	1.49	-448.9942	-1.30		
Khulna03	252.4857	0.64	895.3976***	2.69		
Khulna04	1301.7630***	2.87	1133.5090***	2.67		
Khulna06	424.1526	0.82	-490.4501	-1.53		
Khulna07	1443.9140**	2.34				
Khulna08	1743.7340***	4.78	-1186.2740***	-2.91		
Khulna09	-678.3511	-1.57	562.5902	1.17		
Khulna10	777.0643	1.05	-136.5089	-0.45		
Khulna11	268.2863	0.78	33.8601	0.11		
Barisal2002	-90.8875	-0.16	503.7112	1.28		
Barisal2003	1490.4840**	2.07	-870.1276***	-2.92		
Barisal2004	2085.1860***	4.15				
Barisal2006	1668.7370***	3.55	12.7880	0.03		
Barisal2007	1136.0510	1.18				
Barisal2008	1229.9920***	3.22				
Barisal2009	1345.7560**	2.41	362.5902	0.58		
Barisal2010	1510.7820	2.9	679.2568	1.28		
Barisal 2011	229.6197	0.65	45.5127	0.15		
Chittagong06			-1127.8800	-1.35		
Chittagong10	-529.5385	-0.74	1362.5900*	1.64		
Tangail06			-1704.2480***	-3.19		
Tangail08			40.2533	0.09		
Tangail10	743.9139	1.21	275.0492	0.32		
Tangail11	277.2472	0.39				
Dinajpur05			-1208.4100**	-2.49		
Dinajpur06			623.3761	1.28		
Dinajpur09	140.4615	0.2				
Dinajpur10	405.6151	0.72	75.0492	0.09		
Feni02	-338.2001	-0.67	-1117.5820**	-2.09	-1462.7540	-1.35
Feni03			-267.4098	-0.60		
Feni04			8.0928	0.02		
Feni06	-876.6211	-1.22	828.0847	0.99		
Feni07			71.6223	0.21		
Feni08			-276.7472	-0.57		
Feni09			-637.4098	-1.03		
Feni10			-71.4099	-0.16		
Feni11	2173.3790***	3.02	-234.2334	-0.44		
Rangpur02	1146.0510	1.19				
Rangpur03	1103.9140**	2.24	-504.5927	-1.38		
Rangpur04	2359.8410***	3.46				
Rangpur06	-26.6211	-0.04	-1244.6630**	-2.00		
Rangpur07			1037.5900**	2.16		
Rangpur08	625.5806	1.50				
Rangpur09	179.9853	0.37				
Rangpur10	697.6483	1.47	-452.1612	-1.00		

Variables	HYV Aman model		HYV Boro model		HYV Aus model	
	Coefficient	**t-ratio**	**Coefficient**	**t-ratio**	**Coefficient**	**t-ratio**
Rangpur11	1808.3790**	2.52	22.3549	0.06		
Bhanga03	1719.9170**	2.39				
Bhanga05	1182.5190*	1.77				
Bhanga06	2074.6680***	3.37	-419.6626	-0.67		
Bhanga07	1150.3150**	2.22				
Bhanga08	2898.9450***	6.37	627.2245*	1.64		
Bhanga09	3308.8360***	7.97	757.5126*	1.69		
Bhanga10	1612.7230***	2.62	275.0492	0.42		
Bhanga11	2120.1530***	4.09				
Mymensingh06	-14.1211	-0.03	-541.9125	-1.13		
Mymensingh07			-87.4099	-0.14		
Mymensingh08			-957.5130**	-2.13		
Mymensingh10	645.1641	1.22	755.0492	0.88		
Mymensingh11	1528.3790**	2.13				
Jessore06	115.8789	0.21	-650.9151	-1.44		
Jessore10	1177.2470	1.22				
Jessore11	2564.6680***	4.16				
Bogra07			-237.4098	-0.49		
Sylhet2009					-245.0838	-0.22
Model diagnostics						
Adjusted R^2	0.31		0.43		0.60	
F statistic	5.28***		8.56***		5.86***	
Sample size	884		918		72	