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Economics of Rice Residue Burning in the South-West Region of Bangladesh

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Abstract

This study addresses the economics of rice residue burning in the South-West region of Bangladesh. According to the study estimates, approximately 0.02 million MT rice residue was burnt and 0.20 million US$ equivalent carbon was generated from rice residue burning in the eleven districts of the region in 2005. The study results indicate that straw length, low land and past residue-burning behavior positively and significantly influence current rice residue burning decision. The estimation of production and cost functions indicate that the residue burning in the field generates significant advantages in both production and cost of the successive seasons. The farmers of the burning group enjoy a benefit of US$43/acre on average for the residue burning in the field over the non-burning group. In contrast, the carbon generated from residue burning in the field is equivalent to US$9/acre only! For the very reason, the carbon trading mechanism might not work under the current scenario for addressing the residue burning issue. This study finds limited scopes of addressing the issue from a policy perspective. An R&D effort for working on shortening straw length, shortening time period between plantation and harvesting time, variety development and residue collection might give some insight for handling the issue.

Key Words: Rice residue, Field burning, Removal, Incorporation, Carbon emission, South-West region of Bangladesh

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1. Introduction

Rice is the most important crop of Bangladesh from production volume, value, cultivated land coverage and employment generation perspectives (BBS, 2006). It dominates the cropping patterns of Bangladesh. Depending on agro-economic zones, single, double and triple crops are produced in a piece of land per year in Bangladesh. *Aman* (transplanted and broadcast varieties), *Boro* and *Aus* are the three major types of rice harvested in December-January, March-May and July-August in Bangladesh respectively. Transplanted *Aman* covers about half of Bangladesh's total rice cultivated land followed by *Boro* (one fourth), *Aus* (one sixth) and broadcast *Aman* (one tenth). The transplanted *Aman* is grown almost everywhere in Bangladesh, while broadcast *Aman* is mostly grown in the low-lying areas of the south and north-east parts of the country. In general, double or triple rice cropping is practiced in high land areas. In medium and lowlands, mixed cropping of *Aus* and broadcast *Aman* is a common practice, while in deeply flooded lands, single cropping of either broadcast *Aman* or *Boro* is practiced in Bangladesh (ASB, 2008).

Bangladesh produced 31.32 million metric tons (MT) of rice in 27.86 million acres of land in year 2008-2009 (Deb *et al.*, 2010). The residue derives from this amount of production is also a big amount which has not yet been measured in any study. The rice residue comprises 70% of the total yearly crop residue produced in Bangladesh (ASB, 2008). According to Koopmans and Koppejan (1997), approximately 49.50 million MT of rice residues were produced in Bangladesh in year 1997. Based on a rough calculation on Gadde *et al*. (2009), Thakur (2003), Yang *et al*. (2008), and expert consultation including opinions of the farmers, and field visits, it is estimated that Bangladesh produces around 43.85 million MT[1] of rice residue in 2008-09.

The efficient use of this rice residue entails enormous economic potentiality, which has been neglected so far. Several practices for residue management are: (a) burning in the field, (b) incorporating in the field and (c) removing from the field either for burning along with cow-dung or for feeding cattle herds. The practices influence crop production and soil fertility to varying degrees (Van Doren and Allmaras, 1978). The discussions with experts and farmers and field visits confirm the existence of all the three approaches for managing rice residue in Bangladesh.

This study specifically addresses the residue burning in the field. The burning of residues at fields generates some short-run benefits for the farmers. However, such activities release CO_2 into the atmosphere, and hence it contributes to global warming. The CO_2 emitted from

[1] Assuming Residue/Crop ratio equals 1.4 for rice. See EPA (2011) for details.

residue burning at the field adds nothing or very few to production or society's welfare. However, if the burning takes place at home for cooking or in any other household/industrial usage, it will contribute to production/consumption activities. Therefore, an appropriate strategy to manage crop-residue needs to be developed for farmers in Bangladesh. This study attempts to address this issue. It will quantify the benefits of residue burning in the field in comparison with other practices, develop an understanding on the behavior of the farmers with respect to these practices and suggest appropriate policy measures for proper handling of the rice residue burning problem.

2. Literatures on residue management

Mondal *et al.* (2004) defines the crop residue as the parts of the plants left in the field after crops have been harvested and threshed. It includes straw, stalks, husks and leaves (Hesse, 1984). A large number of literatures are available on the issue. For example, Brady and Weil (2002), Brye *et al.* (2006), EIA (2008), Gadde *et al.* (2009), Ghimire (2007), Gupta *et al.* (2004), Lal (2008), NDEP (2003), Webb *et al.* (2009) and Yadvinder-Singh *et al.* (2004) discuss the concerns and consequences of crop residue burning in the field.

The open burning of crop residue in the field is a common practice in many countries (Gadde *et al.*, 2009). It is a human initiated activity to prepare the fields for the next crop rapidly and inexpensively (Gadde *et al.*, 2009; Webb *et al.*, 2009 and NDEP, 2003). By burning of residue at the field, the farmers have particular benefits in terms of cost and time saving (Lal, 2008). It controls weeds, diseases and pests (Gadde *et al.*, 2009; Lal, 2008 and NDEP, 2003).

On the other hand, field burning of crop residue converts a great deal of nutrients to gaseous form, and they are lost from the site. For example, Ghimire (2007) states that if crop residues are burnt in the field, some of the carbons contained in these materials are lost. The burning of residues gives rise to emissions of heavy metals (HM) and dioxin (Webb *et al.*, 2009). It emits large quantities of CO, CO_2, particulate matter and volatile hydrocarbons into the air (Brady and Weil, 2002). EIA (2008) finds that crop residue burning in the fields emits methane and nitrous oxide. All of these emissions contribute to climate change negatively.

The residue burning causes nutrient and resource losses and adversely affects soil properties and thus calling for improvement in harvesting technologies and residue management systems (Gupta *et al.*, 2004). Similarly, Brye *et al.* (2006) and Yadvinder-Singh *et al.* (2004) find that field burning of crop residue is not environment friendly, undesirable and may not be sustainable. Moreover, Lal (2008) states that field burning have far-reaching negative impacts, such as, air quality degradation and loss of organic materials. According to the literatures on residue burning at the field, the preparation of crop land rapidly and inexpensively, weed control and insect control are the main reasons, while, soil quality degradation and climate change are the main consequences of burning crop residue in the field.

A number of researches focus on the consequences of residue incorporation in the field. The residue incorporation improves soil properties and organic compositions (Mondal *et al.*, 2004; Nepal, 2007 and Yadvinder-Singh *et al.*, 2004). It results in better physical, chemical and biological properties of the soil (Sidhu and Beri, 2008). The returning of residues to the soil has an immense potential for providing the plant nutrients (Nepal, 2007 and Yadvinder-Singh *et al.*, 2004). It increases the N, P, K and C supply to the soil (Bird *et al.*, 2001; Eagle *et al.*, 2000; Eagle *et al.*, 2001; GOI, 1978; Kurihara, 1978; Sharma and Prasad, 2008 and Yadvinder-Singh *et al.*, 2004) that lead to a reduction in fertilizer dependency for crop production (Bird *et al.*, 2001). Some others argue that the incorporation of crop residue in the field does not increase N supply nor does it reduce fertilizer usage in the succeeding crops; however, it supplies N at the later stage (Bird *et al.*, 2002 and Thuy *et al.*, 2008). The incorporation of rice straw in the field also leads to increase in CH_4 emissions (Naser *et al.*, 2007 and Rath *et al.*, 2005).

Residue incorporation leads to sustain and improve crop yield (Badarinath *et al.*, 2006; Mondal *et al.*, 2004; Nepal, 2007; Sharma and Prasad, 2008; Surekha *et al.*, 2006 and Yadvinder-Singh *et al.*, 2004). Meanwhile, Sharma and Prasad (2008) and Surekha *et al.* (2006) ask for coupling green manuring along with residue incorporation for increasing and sustaining grain productivity.

Some researchers compare the residue incorporation with field burning and removal. Williams *et al*. (1972) do not find any significant variation in grain yield for burning and incorporation of residue at the field over a five-year period. However, a number of researchers find that the field incorporation of residue is more advantageous and beneficial than the field burning or removal (Badarinath *et al*., 2006; Eagle *et al*., 2000; Hooker *et al*., 1982; Mondal *et al*., 2004 and Ponnamperuma, 1982). In most of the studies, it is reported that an improvement in crop productivity and soil fertility are the results of residue incorporation in the field.

A number of studies describe the alternative uses of crop residues after removal from the fields. According to CEPA (1997), the most environmentally acceptable solution of the crop residue management problem is to remove and collect the straw from the fields and use for other purposes. Powlson (2008) finds that, greater savings in CO_2 emissions and climate change mitigation can be obtained by removing the straw and using it for energy generation. According to the advisory board on energy in India, 95% of rural households depend on non-commercial energy derived from agricultural and forest resources, particularly fuel wood, crop residues and dung (Pretty *et al.*, 2002). Summers (2001) explores the possibility of using rice straw for energy production. The use of plant products, such as crop residues (e.g. maize cobs, cereal straw, rice husks) or wastes (e.g. chicken manure) for combustion in electricity generation through small-scale gas turbines are some potential fields to explore (Pretty *et al.*, 2002). In summary, the studies explore the possibility of using crop residue for fuel, cattle feeder, cattle litter, energy production, industrial raw material and filling up ditches.

In contrast, the economic consideration of removing residue from the field and using in alternate uses questions the removal approach. Maung (2008) finds that crop residues currently cost much more than coal as an electricity generation feedstock, because they have lower heat content and higher production/hauling costs. Wang *et al.* (2002) suggests for not removing the residue from the field for suppressing wind erosion. Wilhelm *et al.* (2004) report that the removal of crop residue from the field must be balanced against impacting the environment (soil erosion), maintaining soil organic composition and preserving and enhancing productivity. Furthermore, the removal rates will vary based on region, climatic conditions and cultural practices (Wilhelm *et al.*, 2004). Therefore, further studies and inventions are needed to advocate for the removal of residue from the field as an efficient way from an economic viewpoint.

The available and practiced approaches of handling the crop residue management problem have merits and limitations. There is no consensus yet about which approach is the least-cost and most appropriate from society's welfare perspective. A complete study with covering all the direct and indirect costs and benefits of crop residue management is hardly available. Therefore, CEPA (1997) concludes recognizing the necessity of an integrated research covering chemistry, botany, agronomy, biology, ecology, engineering and economics of rice straw for a stable development of the new frontier.

An economic research on the crop residue management problem from Bangladesh perspective is also hardly available. There is no database on the amount of crop residue produced in the country. A specific guideline or policy for handling the produced residue properly is also missing. This study is an attempt to fill the gaps. It investigates the crop residue management practices in the South-West region of Bangladesh. It particularly addresses the residue burning issue and treats the other two approaches (incorporation and removal) as the alternatives and tries to answer the following three research questions:

Research question – 1: What are the main reasons behind the rice residue burning practices in the field?
Research question – 2: What are the benefits of rice residue burning practices in the field?
Research question – 3: What sort of policy measures may be taken for efficient and sustainable management of rice residue?

3. Study area

This study includes the South-West region of Bangladesh as a study site. The Kushtia, Meherpur, Chuadanga, Jhenaidaha, Jessore, Satkhira, Khulna, Bagerhat, Narail, Faridpur and Rajbari districts are considered to define the South-West region of Bangladesh in this study (Map 1). Double cropping patterns dominate the region due to its geographical and other characteristics. This study focuses on farmers producing rice. *Aman* and IRRI are the two main rice types cultivated in this region.

This study considers the information of the district and *thana*[2] level agriculture offices, Bangladesh Statistical Bureau (BBS) and local government units to build up the population list. The population census report 2001 and district-wise community series of Bangladesh has been used to develop the sampling frame. District, *thana*, union and village level information, such as, the number of districts, *thanas* per district, unions per *thana*, villages per union and households per village are compiled from the noted secondary sources. The compilation results reveal that there are 72 *thanas*, 651 unions and 11,434 villages in the study area (BBS, 2006). As the information cited in the secondary sources is of year 2001 and the latest census report of year 2011 is yet to be published, this study attempts to conduct village listing on the selected villages to grasp the up-to-date information. This village list helps to get a clear and

[2] *Thana* is an administrative unit of Bangladesh. A district consists of several *thanas*.

latest picture about the population size, occupational diversity and residue management behavior of the households living in the sample villages.

The study follows a three-stage sampling procedure. Firstly, it randomly selects a sample of 10 *thanas* from the study districts. These 10 *thanas* are the Primary Sampling Units (PSUs) of this study. The study selects 30 villages randomly in the second stage from the selected 10 *thanas* taking 3 from each *thana*. These 30 villages are the Secondary Sampling Units (SSUs) of this study. After selecting the sample villages, a list of farmers, crop varieties, land ownership and residue management practices at the end of the *Aman* season are prepared for each of the selected villages. In Bangladesh, the rice residue of only *Aman* crop is burnt in the field and the rice residue of the two other seasons is not burnt in the field. Therefore, the farmers who cultivated *Aman* crop in year 2010 are listed in the sampling frame. The literature survey, FGD and quick field survey endorse that non-*Aman* cultivating farmers don't burn rice residue in the field at all. The *Aman* cultivating farmers within the sample SSUs are considered as Tertiary Sampling Units (TSUs). A total of 300 TSUs is selected from the 30 SSUs taking 10 from each village systematically. Every n/10th household of the population list of a village is the respondent of this study, where 'n' refers to the total number of listed households of the village. The two big plots of each TSU are intensively surveyed irrespective of residue burning practice or location of the plot.

The final survey is conducted in May 2011. A structured questionnaire is used to conduct the survey on the selected 300 TSUs. The experiences from field visits, FGDs, quick survey and expert consultations are used in finalizing the questionnaire. The questionnaire contains eleven broad sections covering socio-economic characteristics of the respondents in addition to residue management issue. The residue management behavior, harvesting and residue management costs of *Aman* 2010 season (July/Aug. – Nov./Dec.), the production and cost related information of the successive season (Dec./Jan. – Mar./Apr., 2011), past residue management behavior and farmers' perception on the residue management options are the main issues covered by the questionnaire.

4. Methods

4.1 Reason identification

The literatures reveal that time and cost saving and weed control are the main reasons behind field burning of rice residue, which is also supported by the several field visits, FGDs, quick field survey and pilot survey accomplished by the author during 2009-2010 in the South-West region of Bangladesh[3]. Moreover, the visited farmers believe that residue burning at the field improves soil fertility and thus reduces cost of production in the successive seasons and increases productivity. The farmers also informed that the length of the time interval between successive cultivations in the same land, quality of straw, crop variety, land elevation,

[3] The author conducted several field visits during 2009-2010; five FGDs in five villages of Khulna, Narail and Jessore districts during March-April 2010; a quick field survey on 104 agricultural plots of randomly selected 50 farmers from Khulna and Jessore districts in August 2010; and pilot survey on 36 plots of 22 farmers in Khulna, Jessore and Narail districts of the study area in October 2010 for clear understanding of the research issue and finalizing the sampling plan and survey questionnaire.

location of the field, the economic condition of farmers, use of rice straw, past residue management behavior of farmers dictated by belief and inheritance, socio-economic characteristics of the farmers, residue price, cropping intensity (number of crop seasons per year) and crop season are the main factors influencing rice straw burning decision at the field.

This study considers all the above-said factors for tracing out the reasons of residue burning at the field. It attempts to consider the decision of residue burning at the field as a dichotomous dependent measure (Y) with '1 for Yes' and '0 for No'. Based on the literatures and experiences of field visits, fourteen (X_1 to X_{14} [*see Table 6*]) exogenous measures including four dummies for rice variety and two dummies for land elevation are considered to develop a functional relationship between the straw burning decision and some exploratory measures. Using a random-effect logistic regression modeling approach (equation 1 & 2), the reasons of rice residue burning at the field are traced. The random-effect logistic regression analysis helps to answer the first research question. The *thana* level data (i.e., 10 *thanas*) are considered as a random-effect in the logistic model. Statistical software STATA is used to fit the random-effect logistic regression model (i.e., using xtlogit command in STATA).

Equation 1: $Y = f(X_i, r_k)$

where, *i = 1-14; k=1-10*. The above equation (1) can be expressed as follows:

Equation 2: $$Logit\ (p) = Ln\left[\frac{p}{1-p}\right] = \beta_0 + \sum_{i=1}^{14} \beta_i X_i + r_k$$

where, *p* is the probability of '$Y = 1$', i = 1-14 and $r_k \sim N(0, \sigma_r^2)$

N.B.: Table 6 lists the description of the variables.

The effects of all the exogenous variables on the burning decision are evaluated in terms of odd of burning (i.e., odd of burning decision=$e^{\hat{\beta}}$). For the random-effect logistic regression model, an intra-class coefficient (ρ) is calculated. The coefficient $\hat{\rho}$ tells about the proportion of total variance in the outcome (i.e., straw burning decision) that is attributable to the *thana* level.

A Likelihood Ratio (LR) test is also used to evaluate the effect of both the farmer level and *thana* level measures. First, a model is fitted where the probability of straw burning in the field is only function of the area (i.e., *thana*), which is accounted for with an area level random intercept. The same model is refitted after including each of the exogenous variables as a fixed effect in the model, and then a LR test is conducted using the two likelihood values obtained from the two models.

Multicollinearity is a common phenomenon in such a research. Therefore, a pair-wise correlation analysis among the exogenous variables is performed to check how strongly the variables are correlated. In a presence of moderately correlated exogenous variables, the impact of multicollinearity is not too severe in estimating the standard error of the estimated βs. Moreover, multiple logistic regression (equation 3) and linear probability models (equation 4) are used to check the robustness of the findings. The dependent and explanatory measures of equation (3 & 4) are similar to equation (2). Therefore, a comparison is made on the statistical inferences based on the random-effect logistic regression model, multiple logistic regression model and linear probability model. In addition, the marginal effects (*dY/dX*) for the significant explanatory measures of the multiple logistic model are evaluated to trace out the reasons behind the residue burning decision in the field.

Equation 3: $$Logit\ (p) = Ln\left[\frac{p}{1-p}\right] = \gamma_0 + \sum_{i=1}^{14} \gamma_i X_i$$

Equation 4: $$Y = \delta_0 + \sum_{i=1}^{14} \delta_i X_i$$

This study evaluates all of the noted 14 explanatory measures in explaining the reasons behind residue burning in the field. However, the field survey experiences help the author to confine on testing the following two hypotheses in addressing the first research question.

Hypothesis – 1: The length of rice residue influences rice straw burning decision.
Hypothesis – 2: The elevation of land influences rice straw burning decision.

4.2 Benefit estimation

This study tries to estimate the benefits of residue burning in the field. It considers two approaches: (i) production function and (ii) cost function to estimate the benefits. The corresponding main hypotheses are:

Hypothesis – 3: The residue burning in the field generates production advantages in successive season.
Hypothesis – 4: The residue burning in the field generates cost advantages in successive season.

For addressing the third hypothesis, this study estimates the translog production function of equation (5). In addition to plot area, labour, water and fertilizer usage in (*t*) period, the residue management practice of (*t-1*) period is also incorporated as an explanatory measure in the production function of (*t*) period. Later, the residue management practice of (*t-1*) period is replaced with residue management practice of (*t-5*) period in the production function of (*t*) period, keeping all other explanatory and dependent measures similar (equation 6). Such replacement helps to capture the long-run impact of residue management on production. Furthermore, the production functions of equations (5 & 6) are refitted after imposing the restriction of constant returns to scale (CRTS). The estimated coefficients are evaluated for tracing out the production benefits of residue burning in the field.

Equation 5:
$$LnQ = \alpha_0^* + \sum_{j=1}^{4} \alpha_j R_j + \frac{1}{2}\sum_{j=1}^{4} \alpha_{jj} LnR_j^{\;2} + \sum_{j=2}^{4} \alpha_{1j} LnR_1 * LnR_j + \sum_{j=3}^{4} \alpha_{2j} LnR_2 * LnR_j + \alpha_{34} LnR_3 * LnR_4 + \alpha_5 Y$$

Equation 6:
$$LnQ = \mu_0^* + \sum_{j=1}^{4} \mu_j R_j + \frac{1}{2}\sum_{j=1}^{4} \mu_{jj} LnR_j^{\;2} + \sum_{j=2}^{4} \mu_{1j} LnR_1 * LnR_j + \sum_{j=3}^{4} \mu_{2j} LnR_2 * LnR_j + \mu_{34} LnR_3 * LnR_4 + \mu_5 X_{12}$$

N.B.: Table 6 lists the description of the variables.

For addressing the fourth hypothesis, this study estimates the translog cost function of equation (7). In addition to production, and price of land plough, labour, water and fertilizer in (*t*) period, the residue management practice of (*t-1*) period is also incorporated as explanatory measure in the cost function of (*t*) period. Later, the residue management practice of (*t-1*) period is replaced with residue management practice of (*t-5*) period in the cost function of (*t*) period, keeping all other explanatory and dependent measures similar (equation 8). Such replacement helps to capture the long-run impact of residue management on cost. Furthermore, the cost functions of equations (7 & 8) are refitted after imposing the required restrictions (equation 9). The estimated coefficients are evaluated for tracing out the cost advantages of residue burning in the field.

Equation 7:
$$LnC = \rho_0^* + \rho_Q LnQ + \sum_{m=1}^{4} \rho_m LnP_m + \rho_{QQ} LnQ^2 + \frac{1}{2}\sum_{m=1}^{4} \rho_{mm} LnP_m^{\;2} + \sum_{m=2}^{4} \rho_{1m} LnP_1 * LnP_m + \sum_{m=3}^{4} \rho_{2m} LnP_2 * LnP_m + \rho_{34} LnP_3 * LnP_4 + \sum_{m=1}^{4} \rho_{mQ} LnP_m * LnQ + \sum_{m=1}^{4} \rho_{mY} LnP_m * Y + \rho_{QY} LnQ * Y + \rho_5 Y$$

Equation 8:
$$LnC = \omega_0^* + \omega_Q LnQ + \sum_{m=1}^{4} \omega_m LnP_m + \omega_{QQ} LnQ^2 + \frac{1}{2}\sum_{m=1}^{4} \omega_{mm} LnP_m^{\;2} + \sum_{m=2}^{4} \omega_{1m} LnP_1 * LnP_m + \sum_{m=3}^{4} \omega_{2m} LnP_2 * LnP_m + \omega_{34} LnP_3 * LnP_4 + \sum_{m=1}^{4} \omega_{mQ} LnP_m * LnQ + \sum_{m=1}^{4} \omega_{mX12} LnP_m * X_{12} + \omega_{QX12} LnQ * X_{12} + \omega_5 X_{12}$$

Equation 9:
$$\sum_{m=1}^{4} \omega_m = 1; \qquad \sum_{m=1}^{4} \omega_{1m} = \sum_{m=1}^{4} \omega_{2m} = \sum_{m=1}^{4} \omega_{3m} = \sum_{m=1}^{4} \omega_{4m} = 0$$

N.B.: Table 6 lists the description of the variables.

Once the production and cost functions of equations (5-8) are estimated, an attempt is made to calculate the benefits of residue burning in the field, if any. The probable quantifiable sources of benefits are: (A) residue management cost in (*t-1*) period, (B) production cost in (*t*) period, and (C) production in (*t*) period. This study tries to capture all these benefits to compare the results between residue burning and non-burning groups.

4.3 Policy formulation

The analyses findings of the first and second research questions help to answer the third question of this study. This study tries to quantify the carbon generated from the residue burning in the field using both primary and secondary data. It also attempts to use the data of residue price and compensation demanded by the residue burning farmers for giving up residue burning in the field for comparing with the benefits of rice residue burning in the field. In addition, the study attempts to use the concept of market mechanism for addressing the policy implication of the research topic. The time gap between plantation and harvesting periods of *Aman* crop, research & development, crop variety, residue collection process and straw length are some other important aspects that are considered in this study for formulating policy recommendations.

5. Results and Discussions

5.1 Descriptive statistics

The primary occupation of all the respondents of this study is farming. They are male, married and head of the household. The age distribution and educational qualification of the respondents are listed in Table 1. The age group 36 – 50 years dominates the whole sample followed by the age group 51 – 65. More than one-third of the respondents have 1 – 5 years schooling and another more than one third of the respondents have 6 – 10 years schooling. Table 1 also describes that about half of the respondents have 1 – 3 cattle. Another one third of the respondents have 4 – 6 cattle. About half of the surveyed 300 respondents have no access to electricity. About one-fifth of the respondents have one or more *pucca* houses, 59% have one or more semi *pucca* houses and 70% of the respondents have *kacha* houses. About one-fourth of the respondents have less than or equal to one acre of land (Table 1). Another one-third of the respondents have 1 – 2 acres of land. About 79% of the respondents cultivate less than or equal to 5 plots in year 2010. An insignificant portion (less than 1%) of the surveyed farmers uses traditional wooden plough for land cultivation. Although almost all the farmers use a tractor for land cultivation, however, only 9% of them have their own tractor. A similar trend is observed for irrigation equipments. The surveyed farmers manually collect both the rice and residue from the field.

The residue management behavior of the farmers in the South-West region of Bangladesh in S1 (*Aman*) season varies significantly (Table 2). The residue removal from the field dominates among various residue management practices followed by field burning. Complete (100%) field burning of the residue is observed only in 3% plots. However, the upper part removal and lower part field burning are observed in 38% of the surveyed plots. However, if the total acres of all the plots of the respondents are considered, the burning rate decreased to 34% from 41% (=3%+38%). The residue burning practice in the field is widely practiced in Narail, Khulna and Faridpur districts among the surveyed seven districts. The residue management behavior of the farmers is almost consistent over the time period (Table 3).

Table 4 describes the variation in residue management behavior of the respondents from various perspectives. For short straw, removal is the dominating practice. Residue burning in the field is positively associated with the length of rice straw. More than 70 percent respondents burn the rice straw in the field if it grows above 4 feet. The residue which grows less than 4 feet is mostly removed from the field, and the frequency of removal is much higher in case of up to 2 feet long residue. The distance of a plot from the homestead of the farmers influences the residue management practice. According to Table 4, the distance is positively associated with residue burning and incorporation in the field, while it is negatively associated with removal from the field. For low land, residue burning in the field is the dominating trend followed by removal. For high land, the reverse trend is observed among the surveyed plots. For medium land, both the burning and removal practices are observed without anyone's dominance. The table also shows that with the increase of time gap between two successive crop's cultivation, the frequency of residue removal increases. Burning behavior is most likely to happen where the time gap between two crops is short. This result implies that when the farmers are in hurry to cultivate the next crop, they prefer the burning practice.

The open-ended questions regarding the reasons behind farmers' behavior identify 'using the residue as a cattle feeding' is the main reason behind removing from or not burning whole/lower part of straw in the field (Table 5). The farmers also remove or don't burn residue for selling it. The main reasons behind burning the lower part of residue in the field are use as fertilizer, expensive to remove and cleaning the land (Table 5). About half of the respondents think that residue burning in the field generates fertilizer to the field for the successive seasons. Higher removal cost is the main reason behind not removing the residue from the field (Table 5).

5.2 Why do the farmers burn residue in the field?

Table 8 illustrates the random-effect logistic regression results. All the regression coefficients are in the expected sign. The statistically significant variables are: X_2 = Length of rice straw (in feet), X_7 = Low land (4^+ months water logging/year), X_9 = Distance of rice field from farmer's homestead/rice processing area (in meter) and X_{12} = Residue burning in the field in 2006. The results indicate that straw length, low land, distance of the plot and past residue management behavior positively influence residue burning decision of the farmers.

The odd ratio of residue burning in the low land is 6.25 indicating that the odds of residue burning in the low land field is 525% higher as compared to the odds of residue burning at high land after controlling the effects of all other variables considered in the random-effect logistic regression model. Similarly, the odd ratio of the farmers who burnt residue in the past is 111.02 indicating that the odds of burning residue by the said farmers is 11002% higher than the odds of residue burning by the farmers who didn't burn in the past after controlling the effects of all other variables considered in the random-effect logistic regression model (Table 9).

The estimated intra-class coefficient (ρ) for the *thana* level information in the random-effect logistic regression model is 0.18, and it tells that about 18% variability in residue burning decision is explained by the *thana* level measures. The remaining 82% variability in residue burning decision is explained by the farm level measures. A Likelihood Ratio (LR) test is used to evaluate the significance of the intra-class correlation. The chi-square value for the log-likelihood ratio test statistic[4] is 10.04, and hence the intra-class correlation is statistically significantly different from zero. That is, it is important to control the variability of residue burning due to *thana* level measures (i.e., considering *thana* as a random-effect) in evaluating the significance of the farm level measures.

A pair-wise correlation analysis failed to find any severe multicollinearity among the explanatory measures. In addition, the multiple logistic regression results and linear probability model (equation 3 & 4) results almost coincide with the findings of the random-effect logistic regression results (Table 8), which indicate the robustness of the study findings. The odd ratios for low land is 5.50 and for the farmers who burnt residue in the past is 95.78 in the multiple logistic regression model which are also in line with the findings from random-effect logistic regression model.

The marginal effects for X_2 (straw length), X_7 (low land), X_9 (distance of the plot from home) and X_{12} (residue burning in the past) are statistically significant in the random-effect logistic regression model, whereas, the marginal effects for X_2, X_7 and X_{12} are statistically significant in the multiple logistic regression model. According to the results of random-effect logistic regression model noted in Table 10, for 1% increase in straw length, 0.63% more farmers are likely to move from non-burning to burning group; for 1% increase in low land compared to high land, 1.83% more farmers are likely to move from non-burning to burning group; for 1% increase in distance of a plot from home, 0.0005% more farmers are likely to move from non-burning to burning group; and for 1% increase in the number of people as the past residue burner, 4.71% more farmers are likely to move from non-burning to burning group. In the multiple logistic model, the marginal effects for X_2, X_7 and X_{12} are 0.13, 0.40 and 0.81 respectively indicating that for 1% increase in straw length, 1% increase in low land compared to high land and 1% increase in the number of people as the past residue burner, approximately 0.13%, 0.40% and 0.81% more farmers are likely to move from non-burning to burning group, respectively.

5.3 What are the benefits of the farmers for burning residue in the field?

The translog production function estimation results indicate that residue burning of (*t-1*) period has a positive impact on the production of (*t*) period (Model 1 of Table 11), though the coefficient is not statistically significant. However, evidence of residue burning practices in the past significantly influences production (Model 2 of Table 11). For example, for 1% increase in the number of people as past (at *t-5* period) residue burner, production of (*t*) period increases by 0.10%. The same result is observed after imposing the CRTS restriction on the production function (Model 3 & 4 of Table 11).

The translog cost function estimation results also indicate that residue burning of (*t-1*) period generates cost advantages at (*t*) period (Model 1 of Table 12), though the coefficient is not statistically significant. However, evidence of residue burning practices in the past significantly influences the cost (Model 2 of Table 12). For example, for 1% increase in the number of people as a past (at *t-5* period) residue burner, cost of (*t*) period decreases by 1.25%. Almost similar result is observed after imposing the related restrictions, such as,

[4] (–2*[–145.26 – (–140.24)]) = 10.04

equality of cross-partial derivatives (symmetry condition) and linear homogeneity in input prices on the cost function (Model 3 & 4 of Table 12).

Both the production and cost function estimation results endorse the residue burning in the field as an advantageous practice for the farmers. The next step is to quantify the benefits. The author identifies at least three probable sources of benefits, such as, (A) residue management cost in (*t-1*) period, (B) production cost in (*t*) period, and (C) production in (*t*) period. The average values for the cited three sources for both residue burning and non-burning groups are reported in Table 13. The benefit for burning residue in the field over the non-burning group is Tk.[5] 3,204 per acre, though the mean difference is not statistically significant. However, considering the three sources together in calculating the benefits generates the similar result, and it turns out statistically significant. The findings indicate that the farmers who are burning residue in the field are getting benefits from the behavior.

5.4 Thoughts for policy makers

The findings of this study indicate that the residue burning behavior in the field generates benefits for the farmers who are exercising the practice. On average, they are getting Tk. 3,204/acre equivalent benefit for the behavior. Moreover, the study finds statistically significant long-run production and cost advantages for the burning behavior. Therefore, the long-run benefit might be more than the calculated Tk. 3,204/acre. According to the field level survey data, the average compensation demanded by the currently residue burning farmers is Tk. 3,355/acre for giving up the behavior. The claim is higher (Tk. 3,962/acre) for the farmers who are not burning the residue of the surveyed plots, but burning residue of the other plots. It is normally assumed that comparatively lower quality straws are burnt in the field. This statement is evident from the field data also. The average price of the residue is Tk. 6,746/acre for all the respondents, whereas, it is Tk. 5,063/acre for the burning group and Tk. 7,900/acre for the non-burning group[6]. Now the question is how to handle the residue burning problem? The author tries to quantify the carbon generated from the residue burning in the field based on some assumptions and secondary information. Assuming residue/rice ratio = 1.4 (EPA, 2011), length adjustment[7] = average length of burnt residue/average length of all residue, the ratio[8] of full residue burning and lower part of residue burning = 8/92, carbon content[9] for residue burning = 40%, carbon trading price = US$20/MT and 1US$ = Tk. 75, the author finds on overage Tk. 671 equivalent carbon generation for burning rice residue of one acre land (Table 14). As the derived figure (Tk. 671/acre) is far lower from even the quantifiable benefit of residue burning (Tk. 3,204/acre) and the farmers' compensation demand is far higher (Tk. 3,355/acre), the carbon trading mechanism might not work under the current scenario. On the other hand, as it is generating benefits, the farmers also might not stop the practice of residue burning in the field automatically. The author tries to present the scenario in a demand-supply plot for analyzing the issue through the market

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[5] Tk. is the abbreviated version of Taka, is the currency of Bangladesh. 1 Tk. = US$ 0.0133 as on July 17, 2011.

[6] The farmers are classified into burning/ non-burning groups according to residue management practices in their big two plots. Therefore, it is very likely that they may exercise other residue management practices in other plots.

[7] The literatures assume the residue/rice ratio = 1.4 for the average length straw. However, the straw length of the burning group is significantly different and longer than the non-burning group. Therefore, length adjustment is needed to overcome undervaluation.

[8] Field survey (2011).

[9] Aulakh *et al*. (2011) as cited in Yadvinder-Singh *et al*. (2004).

mechanism. The benefit per acre is the price and the service of 'not-burning of residue (in acre land)' is the quantity variable of the demand-supply analysis (Figure 1).

Another important aspect in policy issue is the R&D for handling the rice residue burning problem. This study finds a positive relationship between straw length and residue burning in the field. From rice variety perspective, this study finds a positive relationship between residue burning in the field and *Jabra* and *Balam* varieties, while a negative relationship with IRRI and *Sarna* varieties. This study also finds that the longer the difference between planting and harvesting time, the higher the frequency of residue burning in the field (Figure 2). The filed level data also demonstrate that manual collection of both rice and residue is prevailing in the study area. All these issues attract the attention of R&D. More effort is needed for developing new rice variety/modifying existing variety that may take less time to grow. The straw length issue may also be addressed in R&D. The field data finds almost similar productivity for the four types of varieties. Therefore, an attempt of avoiding *Jabra* and *Balam* varieties might work in reducing residue burning frequency in the field. The prospect of introducing machine instead of the current manual collection for both rice and residue may be explored for better management of the rice residue. However, all the raised issues may be addressed after placing careful attention on productivity, geographical features, water logging condition and salinity issues.

6. Conclusions and policy recommendations

This study addresses the economics of rice residue burning in the South-West region of Bangladesh. The eleven districts of the region cultivated local *Aman* variety in 0.07 million acre land in year 2005 which is 51% of total *Aman* cultivated land in the region. Considering 34% residue burning and average rice production = 1.37 MT/acre and all other related assumptions, approximately 0.02 million MT rice residue was burnt and 0.20 million US$ equivalent carbon was generated in the region in 2005. From Bangladesh perspective, a total of 11.61 million metric ton of *Aman* rice was produced in year 2008-2009. Following the similar steps, it may be estimated that the country burnt 0.30 million MT rice residue and generated 2.39 million US$ equivalent carbon in the year. However, further investigation is needed as the residue burning frequency varies significantly across the regions of the country.

This study finds that straw length, low land and residue burning behavior in the past positively and significantly influences rice residue burning decision in the field. The coherence of the findings from the random-effect logistic regression model, multiple logistic regression model and linear probability model signal the robustness of the study findings. Time gap between two successive seasons, rice variety, use of straw, straw price, firm size and age of farmers are some other factors influencing rice residue burning decision.

The estimation of production and cost functions indicate that the residue burning in the field has significant advantages in both production and cost of successive seasons. The behavior also has cost advantages in residue management cost. The farmers of the burning group enjoy a benefit of Tk. 3,204/acre (US$43/acre) on average for the residue burning in the field over the non-burning group. They claim Tk. 3,355/acre (US$45/acre) for giving up the practice. In contrast, the carbon generated from residue burning in the field is equivalent to Tk. 671/acre (US$9/acre) which is much lower than the derived benefits or claims. For the very reason, the carbon trading mechanism might not work under the current scenario for addressing the residue burning issue.

This study finds limited scope of addressing the residue burning issue from policy perspective. One prospective aspect is R&D activities. An effort for working on straw length, shorter time period between plantation and harvesting time, variety development and residue collection method might give some insight for handling the residue burning issue. However, the R&D activities must be designed only after giving enough consideration on productivity, geographical features, water logging condition, salinity and other issues related to the South-West region of Bangladesh.

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List of Tables

Table 1: Descriptive statistics of the respondents

Criteria	Category	Frequency	Percent (%)
Age distribution (Years)	20 – 35	51	17
	36 – 50	144	48
	51 – 65	91	30
	65^{+}	14	5
	Total	**300**	**100**
Educational qualification (Years of schooling)	No Education	53	18
	1 – 5	115	38
	6 – 10	113	38
	10^{+}	19	6
	Total	**300**	**100**
Cattle ownership (Number)	0 (No Cattle)	16	5
	1 – 3	145	49
	4 – 6	107	36
	7 – 9	22	7
	9^{+}	10	3
	Total	**300**	**100**
Electricity connection	Yes	160	53
	No	140	47
	Total	**300**	**100**
Housing pattern (Number)	*Pucca* House	59	20
	Sami *Pucca* House	177	59
	Kacha House	211	70
Land ownership in year 2010 (in acre)	0.01 – 1.00	77	26
	1.01 – 2.00	104	35
	2.01 – 3.00	61	20
	3.00^{+}	58	19
	Total	**300**	**100**
Number of cultivated plots in year 2010	2 – 5	235	79
	6 – 10	58	19
	10^{+}	7	2
	Total	**300**	**100**
Cultivation equipments	Equipments	Use (%)	Owned (%)
	Tractor	99	9
	Water Pump	95	25
Crop and residue collection	Collection Method	Frequency	Percent (%)
	Manual collection of crop	300	100
	Manual collection of residue	300	100

Source: Author's compilation based on Field Survey (2011).

Table 2: Residue management practices in the surveyed plots

Residue management practice	Frequency	Percent (%)
100% Field burning	17	3
100% Removal from the field	326	54
Upper part removal & Lower part field burning	227	38
Upper part removal & Lower part field incorporation	28	5
Given free	2	0
Total	**600**	**100**

Source: Author's compilation based on Field Survey (2011).

Table 3: Residue management behavior over the time period

Year	Percent of the respondent				
Residue management behavior	2006	2007	2008	2009	2010
100% Field burning	3	3	3	3	3
100% Field removal	53	54	55	54	52
100% Field incorporation	1	1	0	0	0
Upper part removal & Lower part field burning	37	37	39	39	39
Upper part removal & Lower part field incorporation	5	4	3	4	5
Given free	0	0	0	0	1
Missing	1	1	0	0	0
Total	**100**	**100**	**100**	**100**	**100**

Source: Author's compilation based on Field Survey (2011).

Table 4: Residue management practices vs. various factors (in %)

Criteria	**Category**	**BB**	**RR**	**RB**	**RI**	**GF**	**Total**
Length of the residue (Feet)	0 – 2.0	3	92	5	0	0	100
	2.1 – 4.0	2	63	31	4	0	100
	4.1 – 6.0	4	15	71	9	1	100
	6^+	18	12	71	0	0	100
Distance of the plot from home (Km)	0 – 0.5	1	62	32	4	1	100
	0.5 – 1.0	4	43	49	4	0	100
	1.1 – 2.0	5	37	47	11	0	100
	2^+	0	40	47	13	0	100
Land elevation	Low Land	3	29	61	6	0	100
	Medium	3	48	42	6	1	100
	High	2	74	22	1	0	100
Time gap between S1 and S2 seasons (Month)	0 months	3	43	48	5	0	100
	0.01 – 1.00	2	57	38	3	0	100
	1.01 – 3.00	3	55	34	8	1	100
	3^+ months	17	83	0	0	0	100

N.B.: 'BB' refers to 100% Field burning; 'RR' refers to 100% Removal from the field; 'RB' refers to Upper part removal from the field and Lower part field burning; 'RI' refers to Upper part removal from the field and Lower part field incorporation; 'GF' refers to Given free.
Totals may not add to 100 due to rounding error.

Source: Author's compilation based on Field Survey (2011).

Table 5: Reasons behind various residue management practices

Reasons	Percent of the respondent			
	Why don't you burn the whole residue? [N=300]	Why don't you burn the lower part of residue? [N=141]	Why don't you incorporate lower part of residue? [N=251]	Why do you remove the whole residue? [N=195]
Cattle feeding	61	63	17	90
For sell	15	20	20	10
Others	0	0	43	0
No idea	24	17	20	0
All	**100**	**100**	**100**	**100**
	Why do you burn the whole residue? [N=10]	Why do you burn the lower part of residue? [N=138]	Why do you incorporate lower part of residue? [N=42]	Why don't you remove the whole residue? [N=84]
Fertilizer	40	49	74	2
To save time	30	5	0	0
Expensive to remove	30	22	0	48
Clean the land	0	17	0	0
Others	0	7	26	50
All	**100**	**100**	**100**	**100**

Source: Author's compilation based on Field Survey (2011).

Table 6: Variable description

Variables	Variable description
Y	Residue burning decision at field in *t-1* period; 1 = Yes, 0 = No
X_1	Time interval between two successive cultivations in the same land; 1 = More than or equal to one month, 0 = Less than one month
X_2	Length of rice straw (in feet)
X_3	Sarna; IRRI is considered as reference group for creating four dummies (X_3, X_4, X_5 & X_6) of crop variety; 1 = Sarna, 0 = Else
X_4	Balam; IRRI is considered as reference group for creating four dummies (X_3, X_4, X_5 & X_6) of crop variety; 1 = Balam, 0 = Else
X_5	Jabra; IRRI is considered as reference group for creating four dummies (X_3, X_4, X_5 & X_6) of crop variety; 1 = Jabra, 0 = Else
X_6	Others; IRRI is considered as reference group for creating four dummies (X_3, X_4, X_5 & X_6) of crop variety; 1 = Others, 0 = Else
X_7	Low land (4^+ months water logging/year); High (less than 2 months water logging/year) is the reference for creating dummies (X_7 & X_8) of land elevation; 1 = Low land, 0 = Else
X_8	Medium land (2-4 months water logging/year); High (less than 2 months water logging/year) is the reference for creating dummies (X_7 & X_8) of land elevation; 1 = Medium land, 0 = Else
X_9	Distance of rice field from farmer's homestead/rice processing area (in meter)
X_{10}	Farm size (owned land in acre)
X_{11}	Residue collection for cattle feeding; 1 = Yes, 0 = No
X_{12}	Residue burning in the field in 2006 (*t-5* period); 1 = Yes, 0 = No
X_{13}	Age of the farmer (in years)
X_{14}	Residue price (Tk./acre)
Q	Total production in a plot in *t* period (in Tk.)
R_1	Plot area (in acre)
R_2	Use of labour in *t* period (in Tk.)
R_3	Use of water in *t* period (in Tk.)
R_4	Use of fertilizer in *t* period (in Tk.)
C	Total cost in a plot in *t* period (in Tk.)
P_1	Price of land plough in *t* period (in Tk./acre)
P_2	Price of labour in *t* period (in Tk./day)
P_3	Price of water in *t* period (in Tk./acre)
P_4	Price of fertilizer in *t* period (in Tk./acre)

Source: Author's compilation.

Table 7: Summary statistics of the key variables

Variables	Observation	Mean	Standard deviation	Min.	Max.
Y	600	0.41	0.49	0	1
X_1	595	0.82	0.38	0	1
X_2	600	3.63	1.14	1.5	8.5
X_3	600	0.19	0.39	0	1
X_4	600	0.09	0.29	0	1
X_5	600	0.09	0.28	0	1
X_6	600	0.28	0.45	0	1
X_7	600	0.16	0.36	0	1
X_8	600	0.50	0.50	0	1
X_9	600	685.60	873.43	1	15000
X_{10}	600	2.14	1.77	0.06	12.75
X_{11}	600	0.61	0.49	0	1
X_{12}	594	0.40	0.49	0	1
X_{13}	600	47.22	10.96	25	90
X_{14}	600	6746.43	3756.94	2712	17246
Q	600	22601.82	17582.13	0	144000
R_1	600	0.65	0.51	0.13	6
R_2	600	2753.17	2912.19	0	31330
R_3	600	2363.72	2334.99	0	14800
R_4	600	1383.68	1555.60	0	12000
C	597	9213.20	6751.44	618	57210
P_1	600	1686.50	722.88	0	7186
P_2	600	226.06	59.26	0	400
P_3	600	4134.90	3477.82	0	14800
P_4	600	2276.49	2103.54	0	17516

Source: Author's compilation.

Table 8: Reasons behind residue burning in the field

Variables	(1) Random-Effect Logistic Model	(2) Multiple Logistic Model	(3) Linear Probability Model
X_1	-0.63	-0.67	-0.05
	(0.45)	(0.41)	(0.03)
X_2	0.63***	0.59***	0.05***
	(0.18)	(0.16)	(0.02)
X_3	-0.48	-0.16	-0.01
	(0.55)	(0.48)	(0.03)
X_4	0.52	0.83	0.07
	(0.66)	(0.58)	(0.04)
X_5	0.49	0.73	0.07
	(0.77)	(0.69)	(0.05)
X_6	0.39	0.62	0.05*
	(0.46)	(0.40)	(0.03)
X_7	1.83***	1.71***	0.14***
	(0.53)	(0.49)	(0.04)
X_8	0.00	0.11	0.01
	(0.40)	(0.39)	(0.027)
X_9	0.00*	0.00	0.00
	(0.00)	(0.00)	0.00
X_{10}	0.15	0.09	0.00
	(0.12)	(0.10)	(0.01)
X_{11}	-0.13	-0.22	-0.02
	(0.34)	(0.34)	(0.02)
X_{12}	4.71***	4.56***	0.71***
	(0.43)	(0.37)	(0.03)
X_{13}	0.00	0.01	0.00
	(0.02)	(0.01)	(0.00)
X_{14}	0.00	0.00	0.00
	0.00	0.00	0.00
Constant	-5.93***	-5.54***	-0.09
	(1.36)	(1.19)	(0.08)
Observations	589	589	589
Number of group (*thana*)	10	-	-
R-squared	-	-	0.70
Log likelihood	-140.24	-145.26	-
Intra class correlation (rho)	0.18	-	-

N.B.: Standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

Source: Author's compilation based on Field Survey (2011).

Table 9: Odd ratios for reason analysis of residue burning

Variables	(1) Random-Effect Logistic Model	(2) Multiple Logistic Model
X_1	0.53	0.51
	(0.24)	(0.21)
X_2	1.88***	1.80***
	(0.34)	(0.29)
X_3	0.62	0.85
	(0.34)	(0.41)
X_4	1.68	2.30
	(1.10)	(1.34)
X_5	1.63	2.07
	(1.26)	(1.43)
X_6	1.48	1.86
	(0.69)	(0.74)
X_7	6.25***	5.50***
	(3.29)	(2.71)
X_8	1.00	1.12
	(0.40)	(0.43)
X_9	1.00*	1.00
	(0.00)	(0.00)
X_{10}	1.17	1.10
	(0.14)	(0.11)
X_{11}	0.88	0.80
	(0.32)	(0.27)
X_{12}	111.02***	95.78***
	(47.41)	(35.15)
X_{13}	1.00	1.01
	(0.02)	(0.015)
X_{14}	1.00	1.00
	(0.00)	(0.00)
Observations	589	589
Number of group (*thana*)	10	-

N.B.: Standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

Source: Author's compilation based on Field Survey (2011).

Table 10: Marginal effects for reason analysis of residue burning

Variables	(1) Random-Effect Logistic Model	(2) Multiple Logistic Model	(3) Linear Probability Model
X_1	-0.63	-0.15	-0.05
	(0.45)	(0.10)	(0.03)
X_2	0.63***	0.13***	0.05***
	(0.18)	(0.04)	(0.02)
X_3	-0.48	-0.03	-0.01
	(0.55)	(0.10)	(0.03)
X_4	0.52	0.20	0.07
	(0.65)	(0.14)	(0.04)
X_5	0.49	0.17	0.07
	(0.77)	(0.17)	(0.05)
X_6	0.39	0.14	0.05*
	(0.46)	(0.09)	(0.03)
X_7	1.83***	0.40***	0.14***
	(0.53)	(0.11)	(0.04)
X_8	-0.00	0.02	0.01
	(0.40)	(0.08)	(0.027)
X_9	0.00*	0.00	0.00
	(0.00)	(0.00)	0.00
X_{10}	0.15	0.02	0.00
	(0.12)	(0.02)	(0.01)
X_{11}	-0.13	-0.05	-0.02
	(0.36)	(0.08)	(0.02)
X_{12}	4.71***	0.81***	0.71***
	(0.43)	(0.03)	(0.03)
X_{13}	0.00	0.00	0.00
	(0.02)	(0.00)	(0.00)
X_{14}	0.00	-0.00	0.00
	(0.00)	(0.00)	0.00
Observations	589	589	589
Number of group (*thana*)	10	-	-

N.B.: Standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

Source: Author's compilation based on Field Survey (2011).

Table 11: Production function estimation

Variables	(1) logQ (No restriction; Burning of *t-1* period)	(2) logQ (No restriction; Burning of *t-5* period)	(3) logQ (CRTS; Burning of *t-1* period)	(4) logQ (CRTS; Burning of *t-5* period)
LnR_1	0.75***	0.71***	0.30*	0.28*
	(0.23)	(0.23)	(0.16)	(0.16)
LnR_2	0.76***	0.78***	0.66***	0.68***
	(0.11)	(0.11)	(0.11)	(0.11)
LnR_3	-0.052	-0.08	-0.13	-0.16
	(0.11)	(0.11)	(0.10)	(0.10)
LnR_4	0.15	0.17	0.16	0.20*
	(0.11)	(0.12)	(0.11)	(0.12)
LnR_{11}	-0.00	-0.02	-0.03	-0.03
	(0.10)	(0.10)	(0.02)	(0.02)
LnR_{22}	-0.00	-0.00	0.03**	0.03*
	(0.02)	(0.017)	(0.02)	(0.02)
LnR_{33}	0.05***	0.05***	0.06***	0.06***
	(0.02)	(0.02)	(0.02)	(0.02)
LnR_{44}	0.09***	0.09***	0.09***	0.09***
	(0.02)	(0.02)	(0.02)	(0.02)
LnR_{12}	-0.07**	-0.06**	0.08***	0.08***
	(0.03)	(0.03)	(0.02)	(0.02)
LnR_{13}	-0.03	-0.04	-0.04**	-0.04***
	(0.03)	(0.03)	(0.02)	(0.02)
LnR_{14}	0.08**	0.08***	-0.01	-0.01
	(0.03)	(0.03)	(0.02)	(0.02)
LnR_{23}	-0.03***	-0.03***	-0.02**	-0.02**
	(0.01)	(0.01)	(0.01)	(0.01)
LnR_{24}	-0.08***	-0.08***	-0.09***	-0.09***
	(0.01)	(0.01)	(0.01)	(0.01)
LnR_{34}	0.01	0.01	0.00	0.00
	(0.01)	(0.01)	(0.01)	(0.01)
Y	0.04	-	0.04	-
	(0.05)	-	(0.05)	-
X_{12}	-	0.10*	-	0.11**
	-	(0.05)	-	(0.05)
Constant	5.63***	5.55***	5.83***	5.73***
	(0.45)	(0.50)	(0.49)	(0.49)
Observations	600	594	600	594
R-squared	0.63	0.63	-	-

N.B.: Standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

Source: Author's compilation based on Field Survey (2011).

Table 12: Cost function estimation

Variables	(1) LogC (No restriction; Burning of *t-1* period)	(2) LogC (No restriction; Burning of *t-5* period)	(3) logC (CRTS; Burning of *t-1* period)	(4) logC (CRTS; Burning of *t-5* period)
LnQ	-0.57	-0.41	-1.59***	-1.57***
	(0.59)	(0.60)	(0.31)	(0.32)
LnP_1	2.80***	3.22***	1.04***	1.06***
	(0.91)	(0.92)	(0.39)	(0.39)
LnP_2	2.13*	2.75**	-0.61	-0.55
	(1.21)	(1.23)	(0.38)	(0.38)
LnP_3	0.044	0.11	0.28***	0.28***
	(0.21)	(0.20)	(0.09)	(0.09)
LnP_4	0.35	0.12	0.29**	0.22
	(0.30)	(0.30)	(0.14)	(0.14)
LnQQ	0.30***	0.30***	0.28***	0.28***
	(0.03)	(0.03)	(0.03)	(0.03)
LnP_{11}	0.01	0.01	0.04**	0.04**
	(0.02)	(0.02)	(0.02)	(0.02)
LnP_{22}	0.19**	0.20**	-0.01	-0.01
	(0.08)	(0.09)	(0.03)	(0.03)
LnP_{33}	0.02**	0.02*	0.02*	0.02*
	(0.01)	(0.01)	(0.01)	(0.01)
LnP_{44}	0.01	0.01	0.01	0.01
	(0.01)	(0.01)	(0.01)	(0.01)
LnP_{12}	-0.30**	-0.37***	-0.01	-0.01
	(0.14)	(0.14)	(0.02)	(0.02)
LnP_{13}	-0.01	-0.01	-0.04***	-0.04***
	(0.02)	(0.02)	(0.01)	(0.01)
LnP_{14}	-0.02	-0.02	0.01	0.01
	(0.02)	(0.02)	(0.02)	(0.02)
LnP_{23}	0.04	0.027	0.03**	0.03**
	(0.02)	(0.02)	(0.01)	(0.01)
LnP_{24}	0.03	0.06	-0.01	-0.00
	(0.04)	(0.04)	(0.02)	(0.02)
LnP_{34}	-0.01**	-0.01**	-0.01**	-0.01**
	(0.00)	(0.00)	(0.00)	(0.00)
LnP_1Q	-0.10**	-0.10**	-0.10**	-0.10**
	(0.04)	(0.04)	(0.04)	(0.04)
LnP_2Q	-0.12	-0.15*	0.08**	0.08*
	(0.08)	(0.09)	(0.04)	(0.04)
LnP_3Q	-0.01	-0.01	-0.01	-0.01
	(0.01)	(0.01)	(0.01)	(0.01)
LnP_4Q	-0.03**	-0.02*	-0.02	-0.02
	(0.01)	(0.02)	(0.01)	(0.01)
LnQY	-0.02	-	-0.04	-
	(0.04)	-	(0.04)	-
$LnQX_{12}$	-	0.02	-	-0.01
	-	(0.04)	-	(0.04)
LnP_1Y	0.02	-	-0.027	-
	(0.05)	-	(0.05)	-
LnP_1X_{12}	-	0.03	-	-0.03
	-	(0.05)	-	(0.05)
LnP_2Y	0.09	-	0.09	-
	(0.08)	-	(0.08)	-
$LnP_2\ X_{12}$	-	0.17**	-	0.07
	-	(0.08)	-	(0.08)

Variables	**(1) LogC (No restriction; Burning of *t-1* period)**	**(2) LogC (No restriction; Burning of *t-5* period)**	**(3) logC (CRTS; Burning of *t-1* period)**	**(4) logC (CRTS; Burning of *t-5* period)**
LnP_3Y	0.01	-	0.00	-
	(0.02)	-	(0.02)	-
$LnP_3 X_{12}$		-0.01	-	-0.01
		(0.02)	-	(0.02)
LnP_4Y	-0.03*	-	-0.03	-
	(0.02)	-	(0.02)	-
$LnP_4 X_{12}$	-	-0.01	-	-0.00
	-	(0.02)	-	(0.02)
Y	-0.28	-	0.30	-
	(0.68)	-	(0.65)	-
X_{12}	-	-1.25*	-	-0.02
	-	(0.71)	-	(0.66)
Constant	-11.10	-14.34*	7.16***	7.15***
	(7.46)	(7.59)	(1.69)	(1.71)
Observations	597	591	597	591
R-squared	0.86	0.86	-	-

N.B.: Standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

Source: Author's compilation based on Field Survey (2011).

Table 13: Benefit of residue burning in the field

Sources of benefits	Non-Burning group	Burning group	Mean difference	t statistics
Average residue management cost in *t-1* period (Tk./acre)	15,738	15,525	213	0.31
Average production cost in *t* period (Tk./acre)	21,539	24,152	2,613	-1.79
Average production in *t* period (Tk./acre)	6,056	5,678	378	1.31
Total benefit from three sources (Tk./acre)	**-**	**-**	**3,204**	**-**
Benefits for considering the three sources together (Tk./acre)	-182	3,022	3,204	-1.92

Source: Author's compilation based on Field Survey (2011).

Table 14: Calculation of carbon emission from rice residue burning in the field

	Average rice production (Mound / acre)	Residue (Mound / acre)	Residue (MT / acre)	Burnt residue (MT / acre)	Carbon (MT / acre)	Carbon equivalent (US$ / acre)	Carbon equivalent (Tk. / acre)
No burning	36.14	50.60	1.92	-	-	-	-
Burning	31.37	51.79	2.07	1.12	0.45	8.95	671
All	**34.20**	**47.88**	**2.04**	**-**	**-**	**-**	**-**

N.B.: Assuming residue/rice ratio = 1.4, length adjustment = average length of burnt residue/average length of all residue – for burning group only, full residue/lower part of residue burnt ratio = 8/92, carbon content for burning residue = 40%, carbon trading price = US$20/MT and 1US$ = Tk. 75.

Source: Authors compilation.

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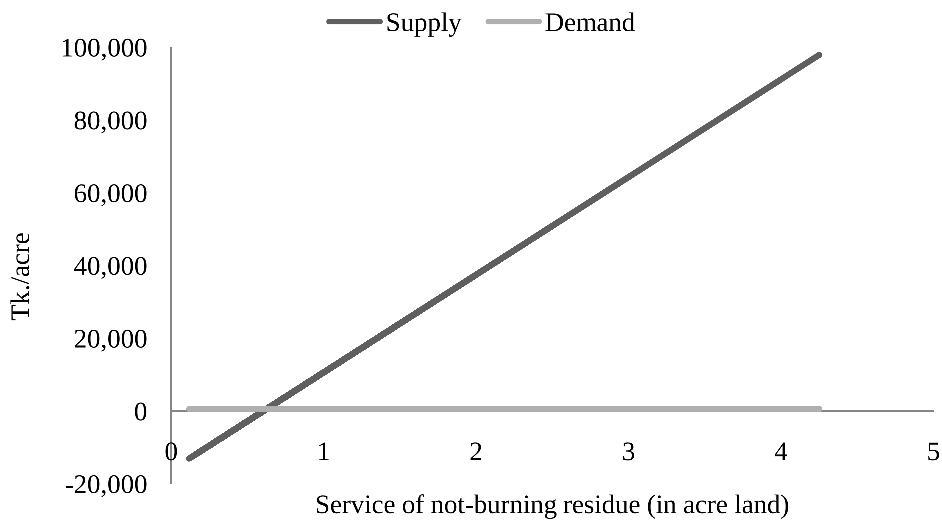


Figure 1: Demand-Supply of the service 'not-burning of residue'

Source: Author's compilation based on Field Survey (2011).

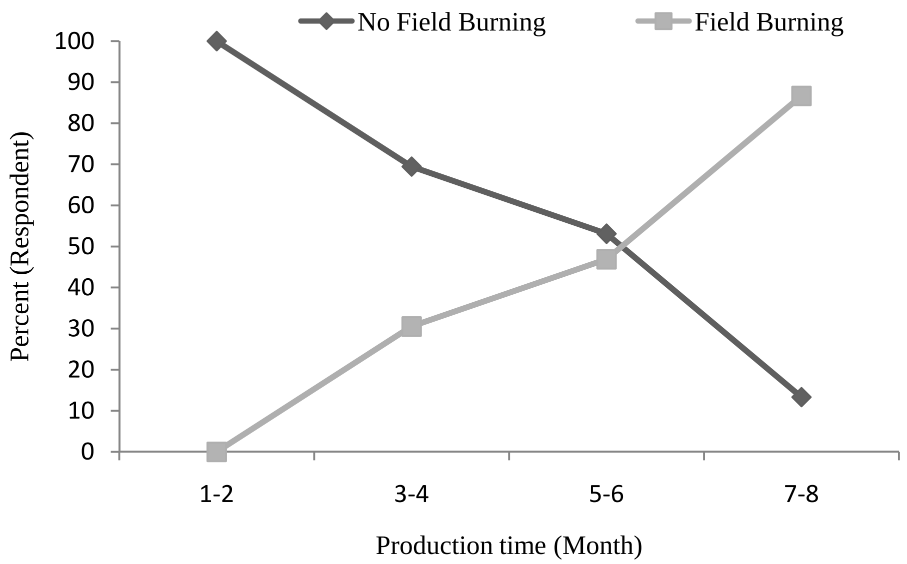
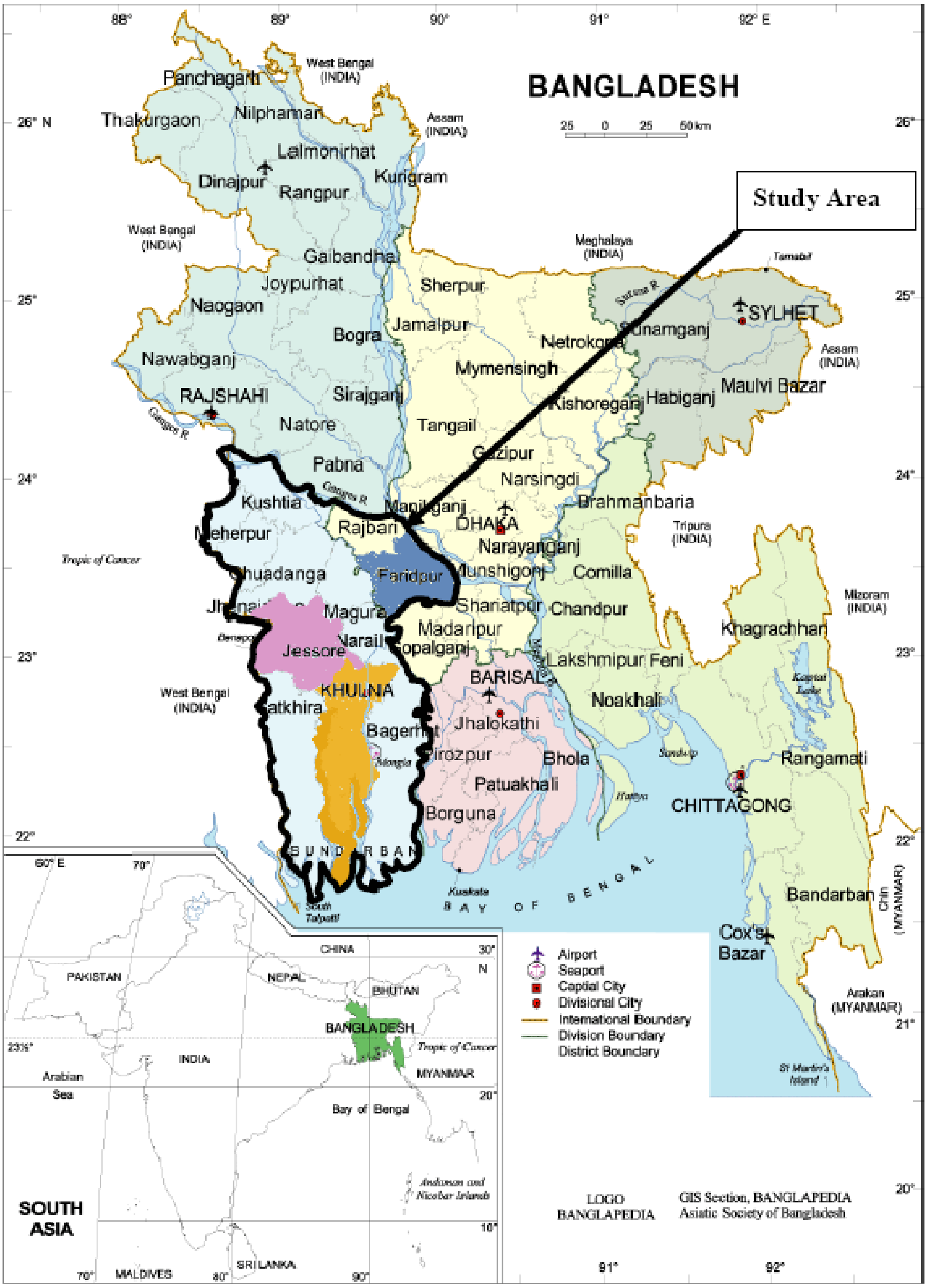


Figure 2: Field burning of residue vs. production time

Source: Author's compilation based on Field Survey (2011).

Map 1: The study area



Source: Author's compilation based on ASB (2008).