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Options and Determinants of Rice Residue Management Practices in the South-West Region of Bangladesh

Mohammed Ziaul Haider

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Abstract

Farmers in Bangladesh burnt an estimated 3.14 million metric tons of rice residue in 2010. Rice residue burning contributes to climate change and pollution through the release of gaseous and particulate matter. Thus, this study examines options for managing rice residue and the factors that determine its management in the south-west region of Bangladesh. Study results indicate that while straw length, low-elevation land and distance of the plot from the homestead positively and significantly influence the decision to burn rice residue, residue price has a negative effect. Farmers who burn residue enjoy a net annual benefit of USD 43-45/acre on average relative to farmers who don't burn. This benefit accrues because productivity is higher by about 9 percent in fields where burning occurs and the costs of rice harvesting, including residue burning, are lower by about 10 percent. Aggregating from our sample survey and assuming similar trends in the rest of Bangladesh, our study estimates that farmers would need to be subsidized approximately USD 2.10 million per year in order to avoid rice residue burning in Bangladesh. This amounts to approximately 4% of the subsidies currently available to farmers for fertilizer use and other purposes. Our study also proposes alternate strategies such as support for purchasing new varieties of seeds and investment in information and education to persuade farmers to move to short-straw varieties on high and medium-elevation lands. Another option might be to switch from residue burning to incorporation. Research and development efforts into shortening straw length, shortening the time-period required between harvesting and planting and new rice varieties may also help to mitigate residue burning.

Key Words: Rice residue, Field burning, Residue removal, Bio-mass burning, Bangladesh.

Options and Determinants of Rice Residue Management Practices in the South-West Region of Bangladesh

1. Introduction

Biomass and fossil-fuel burning are two major contributors to gaseous (such as carbon monoxide) and particulate (aerosol) pollution around the world (Gustafsson et al., 2009; Szidat, 2009; UNEP and C[4], 2002). In recent years, researchers have emphasized the role of open burning of crop residue in the field in generating gaseous and particulate emissions (Badarinath et al., 2006; Zhang et al., 2008). Ramanathan and Carmichael (2008) indicate that biomass and wood burning result in black carbon, which is the second largest contributor to current global warming after carbon dioxide. FAO (2002), for instance, states that biomass burning and crop residues account for about 18 percent of global emissions. Moreover, as Long et al. (1998) and Auffhammer et al. (2006) have shown, residue burning can adversely affect both the health of the population and the climate.

A regional emerging climate issue in South Asia is the presence of Atmospheric Brown Clouds (ABC). These clouds linger over South Asia with implications for regional climate, agricultural productivity, glacial melting and health (Auffhammer et al., 2006; UNEP, 2008). Gustafsson et al. (2009) suggest that farmers' burning agricultural residue in the field is a major contributor to the ABC. However, residue and indoor fuel burning also support many local production and consumption activities. Our study is an investigation into some of these activities in order to understand why farmers burn crop residue and whether they may be willing to reduce burning.

Rice is the most important crop of Bangladesh from the perspectives of production volume, value, cultivated land coverage and employment generation (BBS, 2011). As part of the harvesting of rice and field preparation, farmers burn a great deal of rice residue. According to Koopmans and Koppejan (1997), the amount of rice residue produced in Bangladesh in 1997 was approximately 49.50 million metric tons (mt). Rice residue comprises 70 percent of the total yearly crop residue produced in Bangladesh (ASB, 2008). In 2010, Bangladesh produced 32 million mt of rice in 28 million acres of land (BBS, 2011). Based on a rough calculation by Gadde et al. (2009), Thakur (2003), Yang et al. (2008), as well as consultations with experts, including the opinions of farmers and field visits, we estimate that the amount of rice residue produced in Bangladesh in 2010 to be around 45 million mt.[1]

In order to manage rice residue in the field, farmers in Bangladesh have three options: (a) burn residue in the field, (b) incorporate residue into the field, and (c) remove residue from the field, either for burning along with cow-dung or for feeding cattle herds. These practices, according to van Doren and Allmaras (1978), influence crop production and soil fertility to varying degrees.

This study focuses on the issue of residue burning in the field while treating the other two approaches (incorporation and removal) as alternatives. It attempts to (a) quantify the benefits of residue burning in the field relative to alternative practices, (b) develop an understanding on the behavior of the farmers with respect to these practices, and (c) suggest appropriate policy measures to address the rice residue burning problem. For this purpose, using primary data collected from the south-west region of Bangladesh, it tries to answer the following three research questions:

1. What are the main reasons behind the rice residue burning practice in the field?
2. What are the benefits of rice residue burning practice in the field to farmers?
3. What policy measures may be taken for the efficient management of rice residue?

[1] This is assuming that the residue/crop ratio equals 1.4:1 for rice. See EPA (2011) for details.

This study finds that while straw length, low-elevation land and distance of the plot from the homestead positively and significantly influence the rice residue burning decision, residue price negatively and significantly influences the residue burning decision of farmers. The results also indicate that farmers who burn residue derive a benefit from residue burning in the field over those who do not burn residue. We propose subsidies for the purchase of new varieties of seeds and/or education in order to persuade farmers to move to short-straw varieties on high/medium-elevation lands; to switch from residue burning to incorporation; and to employ research and development efforts into shortening straw length, shortening the time-period between planting and harvesting time, residue collection, and rice variety development that would mitigate the problem under consideration.

This paper consists of six sections. The first section includes background and research questions of the study. Section 2 deliberates an overview of the literatures on residue management. Section 3 describes the study area. Section 4 discusses the methodology of the paper including behavioral responses of the farmers and estimation strategy. Section 5 presents the results and discussion. Finally, section 6 concludes the study putting some policy recommendations.

2. The Literature on Residue Management

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 for the purpose of preparing the fields for the next crop rapidly and inexpensively (Gadde et al., 2009; NDEP, 2003; Webb et al., 2009). By burning residue in the field, farmers derive specific benefits such as cost- and time-savings (Lal, 2008). Residue burning is also a means to control weeds, diseases and pests (Gadde et al., 2009; Lal, 2008; NDEP, 2003).

On the other hand, field burning of crop residue converts a great deal of nutrients to gaseous form, which is then lost from the site. Ghimire (2007), for example, has shown how some of the carbons contained in the crop residue is lost if it is burnt in the field. Moreover, the burning of residue gives rise to emissions of Heavy Metals (HM) and dioxin (Webb et al., 2009). While a study by Brady and Weil (2002) has shown that crop residue burning in the field emits large quantities of CO, CO_2, particulate matter and volatile hydrocarbons into the air, EIA (2008) has found that it emits methane and nitrous oxide. These emissions indubitably contribute to climate change.

Since crop residue burning causes nutrient and resource losses while adversely affecting soil properties, there have been calls for improvements in harvesting technologies and residue management systems (Gupta et al., 2004). Brye et al. (2006) and Yadvinder-Singh et al. (2004), for instance, have argued that field burning of crop residue is not only environmentally-unfriendly and undesirable but may also not be sustainable. Lal (2008) sees field burning of residue to have far-reaching negative impacts, such as air quality degradation and loss of organic materials. Thus, the main reasons behind residue burning in the field, according to the available literature, can be attributed to the desire on the part of farmers for rapid and inexpensive preparation of crop land and weed and insect control. On the other hand, soil quality degradation and climate change are the main adverse consequences of this practice.

A number of researchers have also focused on the consequences of residue incorporation in the field. Some of them indicate that the residue incorporation improves soil properties and organic compositions (Mondal et al., 2004; Nepal, 2007; Yadvinder-Singh et al., 2004). Others have shown that it improves the physical, chemical and biological properties of the soil (Sidhu and Beri, 2008). Still others have demonstrated that the return of residues to the soil has immense potential for providing plant nutrients (Nepal, 2007; Yadvinder-Singh et al., 2004) because it increases the N, P, K and C supplies to the soil (Bird et al., 2001; Eagle et al., 2000; Eagle et al., 2001; GOI, 1978; Kurihara, 1978; Sharma and Prasad, 2008; Yadvinder-Singh et al., 2004), which in turn lead to a reduction in fertilizer dependency for crop production (Bird et al., 2001). However, other researchers have argued that the incorporation of crop residue in the field does not increase the N supply; nor does it reduce fertilizer usage in the succeeding crops although it supplies N at a later stage (Bird et al., 2002; Thuy et al., 2008). The incorporation of rice straw in the field also leads to an increase in CH_4 emissions, according to Naser et al. (2007) and Rath et al. (2005).

Many studies have also demonstrated that residue incorporation leads to a sustained and improved crop yield (Badarinath et al., 2006; Mondal et al., 2004; Nepal, 2007; Sharma and Prasad, 2008; Surekha et al., 2006;

Yadvinder-Singh et al., 2004). Meanwhile, Sharma and Prasad (2008) and Surekha et al. (2006) have asked for a coupling of green manuring with residue incorporation for increased and sustained grain productivity.

Some researchers have also compared the practice of 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 in the field over a five-year period. However, a number of researchers have found that field incorporation of residue is more advantageous and beneficial than field burning or removal (Badarinath et al., 2006; Eagle et al., 2000; Hooker et al., 1982; Mondal et al., 2004; Ponnamperuma, 1982). Most of these studies report that an improvement in crop productivity and soil fertility is the result of residue incorporation in the field.

A number of studies have described the alternative uses of crop residue after removal from the field. According to CARB (1997), the most environmentally acceptable solution to the crop residue management problem is to remove and collect the straw from the fields and use it for other purposes. Powlson et al. (2008) find 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 percent of rural households depend on non-commercial energy derived from agricultural and forest resources, particularly fuel wood, crop residue and dung (Pretty et al., 2002). A study by Summers (2001) has explored the possibility of using rice straw for energy production. Thus, the use of plant products such as crop residue (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 among potential fields to explore for this purpose (Pretty et al., 2002). In sum, these studies explore the possibility of using crop residue for alternative uses after removing from the field.

In contrast, studies focusing on the economic dimension to removing residue from the field and using it for alternative purposes question the feasibility of the removal approach. Maung (2008) finds that crop residue currently costs much more than coal for electricity generation because it has a lower heat content and higher production/hauling costs. Wang et al. (2002) argue against removing the residue from the field in order to suppress wind erosion. Wilhelm et al. (2004) suggest that the removal of crop residue from the field must be balanced against the adverse impact on the environment (due to soil erosion) and the need to maintain soil organic composition for the purpose of preserving and enhancing productivity. Furthermore, as Wilhelm et al. (2004) have pointed out, removal rates will vary based on region, climatic conditions, cultural practices, and alternative uses. Therefore, further studies and inventions are needed from an economic perspective before advocating the removal of residue from the field as the most efficient and effective solution to the problem of residue burning.

As evident from the above survey of extant literature, the available approaches to address the problem of crop residue management contain both merits and de-merits. There is no consensus yet about any approach which is the least expensive, yet most appropriate, from the perspective of the society's well-being. A comprehensive study covering all the direct and indirect costs as well as benefits of crop residue management is hardly available. Therefore, the CARB (1997) study, for instance, concludes by recognizing the necessity of an integrated research covering the chemistry, botany, agronomy, biology, ecology, engineering and economics of rice straw to develop a stable new solution to the problem of rice straw management.

To date, there are few studies adopting an economic approach to the study of residue management. Studies that trace the determinants of crop residue burning in the field are also scarce. Similarly, the concomitant economic costs and benefits of residue burning in the field have also not been addressed to date in the available literature. The present study fills some of these research gaps. It is arguably the first study that uses farm-level data to address the residue burning issue in the case of Bangladesh. Since there is neither a database on the amount of crop residue produced in the country nor a specific guideline or policy for the proper management of the residue produced, the findings of the research will do much to fill a significant lacuna in knowledge in this particular field.

3. Study Area

The study focuses on the south-west region of Bangladesh. For the purposes of this study, the Kushtia, Meherpur, Chuadanga, Jhenaidaha, Jessore, Satkhira, Khulna, Bagerhat, Narail, Faridpur and Rajbari districts comprise the south-west region of Bangladesh (see Map 1). Double cropping patterns dominate the region due to its geographical and other characteristics. The study focuses on rice farmers, *Aman* and *IRRI* being the two main rice varieties cultivated in this region.

We compile district, *thana*[2], union and village level information, such as the number of districts, *thanas* per district, unions per *thana*, villages per union and households per village based on the following secondary sources: information from the district and *thana* level agriculture offices, the Bangladesh Bureau of Statistics (BBS), and local government units. We use the Census Report 2001 and the district-wise community information of Bangladesh in order to develop the sampling frame. The compilation results reveal that there are 72 *thanas*, 651 unions and 11,434 villages in the study area (BBS, 2007). As the information cited in the secondary sources is for 2001 because the latest Census Report for 2011 is yet to be published, this study attempts to list village characteristics of the selected sample villages in order to elicit up-to-date information relevant to the study. These listings enable us to arrive at clear and up-to-date information on population size, occupational diversity and residue management behavior of the households living in the sample villages.

The study follows a two-stage sampling procedure. Firstly, we selected a sample of 10 *thanas* randomly from the study districts and, in turn, selected 30 villages randomly from the selected 10 *thanas* taking 3 from each *thana*. These 30 villages constitute the Primary Sampling Units (PSUs) of the 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 was prepared for each of the selected villages. In the case of Bangladesh, the rice residue of the *Aman* crop is burnt in the field while the rice residue of the two other seasons is not burnt in the field.[3] The literature survey, FGD and a quick field survey confirm that non-*Aman* cultivating farmers do not burn rice residue in the field. Therefore, we only considered farmers who cultivated an *Aman* crop in the year 2010 when selecting sample farmers. We selected a total of 300 farming households from the 30 PSUs taking 10 from each village using the systematic sampling method. We started from a side of a village and took every n/10th household of the population list of the village as the respondent of this study, where 'n' refers to the total number of listed households of the village. We surveyed the two biggest plots of each sample household irrespective of residue burning practice or location of the plots.

We conducted the final survey in May 2011. We used a structured questionnaire to conduct the survey on the selected 300 farm households. Based on knowledge gained from field visits, FGDs, quick survey and expert consultations, we finalized the questionnaire. The questionnaire contained eleven broad sections covering the socio-economic characteristics of the respondents in addition to the residue management issue. The residue management behavior, the 'rice 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' perceptions of the residue management options were the main issues covered by the questionnaire.

4. Methods

4.1 Behavioral Responses of Farmers

The study considers the decision of residue burning in the field as a dichotomous dependent measure (Y_{t-1}) with '*1 for Yes*' and '*0 for No*'. A residue burning farmer, for the purposes of this study, is one who burns either the lower part or the whole part of rice straw in the field ($Y_{t-1}=1$). Based on the literature review and the likely behavioral responses of farmers, we use nine (X_{1t} to X_{9t} [see Table 1]) variables as regressors.

There is generally some variation in the time-interval between the two successive crops planted by farmers. This is due to variation in cropping pattern, geographical location and water-logging conditions. The residue management behavior depends on that time interval (X_{1t}), which is measured as a dummy variable with '*1 for more than or equal*

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

3 The farmers do not burn the residue of non-*Aman* crop (*Aus* and *Boro*) in the field as it grows in the dry season and produces comparatively shorter and better quality straw. They use that straw for cattle feeding and cooking fuel or store it for using in the rainy season. However, the *Aman* rice straw which grows under water in the low- and medium-elevation land during the rainy season is burdensome to the farmers and they burn that straw in the field.

to one month' and '*0 for less than one month*' interval. We use this as a dummy variable as some of the respondent farmers gave a range of days instead of specific days and others specified months. In determining the interval, we take the duration between harvesting one crop and initiating preparations to cultivate the next crop. This study hypothesizes that the shorter the interval the busier the farmers would be and therefore more likely to burn rice residue in the field in order to shorten the land preparation time.

Straw length (X_{2t}) also influences the residue management behavior of farmers. Given the demand for the short straw as animal feed, the longer straw is burdensome to farmers. Since the length and quality of the rice straw are therefore inversely related, we expect straw length and residue burning to be positively associated. This study measures straw length in feet.

The elevation of agricultural land is another important characteristic which affects the crop type, production volume, cropping intensity, straw quality and residue burning decision. This study considers three types of land elevations: (i) Low-elevation land (4^+ months of water logging/year); (ii) Medium-elevation land (2-4 months of water logging/year); and (iii) High-elevation land (less than 2 months of water logging/year). We assume a positive relationship between residue burning in the field and low-elevation land because of the lower quality and longer straw produced in the low-elevation land and vice-versa. We consider high-elevation as a reference and use two dummies: X_{3t} for low-elevation and X_{4t} for medium-elevation land.

We use the distance (X_{5t}) of a rice field from a farmer's homestead as a proxy for transportation cost. The farmers may not be interested in collecting the straw of rice fields located at a distance. The distance is expressed in kilometer (km) in this study.

There is a proportional relationship between farm size (X_{6t}) and the amount of rice residue. We measure farm size by the owned land of the farmers in acre. While large land holders might not be interested in collecting all residue produced in the land, small land holders may use such residue as an important source of cooking fuel.

Rice residue is mainly used as animal feed in Bangladesh. Therefore, this study hypothesizes an inverse relationship between cattle ownership (X_{7t}) and the burning of rice residue in the field. We measure it as the number of cattle per acre of land.

The age of the farmers (X_{8t}) measures experience, skill, knowledge and consciousness regarding the adverse impacts of residue burning which might have some influence on the residue management decision. The price of residue (X_{9t}) is another explanatory variable which is expected to be negatively associated with the residue burning decision since we expect the farmers to behave rationally. We measure it in thousand Tk.[4] for the residue grown in per acre of land.[5] The price of residue varies due to variation in straw quality, rice variety, distance of the plot from homestead, and survey area.

The determinants of alternative management practices with regard to rice residue are mostly identified based on the existing literature, field visits, and FGDs in the south-west region of Bangladesh.[6] We present the descriptive statistics of all relevant variables in Table 1. Given below are the two main hypotheses that are intended to answer the first question:

H_1: The length of rice residue influences the rice straw burning decision;

H_2: The elevation of land influences the rice straw burning decision.

4 Tk. is the abbreviated version of Taka, which is the currency of Bangladesh. 1 Tk.=USD 0.0133 on July 17, 2011.

5 As the residue is mostly sold in the field instead of in any formal market place, the exact volume data of the produced and sold residue is not available. The better quality straw derived from shorter rice straw, collected from the nearer rice fields, and from favorable rice varieties such as *IRRI* and *Sarna* is usually sold. This residue transaction takes place in per acre basis and is mostly informal which takes place in the field instead of any formal market place. We calculate the price of residue from the primary data provided by the respondents.

6 The author conducted several field visits during 2009-2010; five FGDs in the five villages of Khulna, Narail and Jessore districts during March-April 2010; a quick field survey of 104 agricultural plots of randomly selected 50 farmers from Khulna and Jessore districts in August 2010; and a pilot survey of 36 plots of 22 farmers in Khulna, Jessore and Narail districts of the study area in October 2010 in order to clearly understand the research issue and to finalize the sampling plan and survey questionnaire.

4.2 Estimation Strategy

Since the dependent variable is binary, we estimate a logit regression model (equation 1) to assess the reasons for rice residue burning. We also estimate the random effect logit model (equation 2), *thana* level fixed effect logit model (using 9 dummies for 10 *thanas*), and linear probability models to check the robustness of the findings. In each of the models, we use the same dependent variable for the same set of explanatory variables.

$$L_i = \ln\left[\frac{p_i}{1-p_i}\right] = \beta_0 + \sum_{i=1}^{9} \beta_i X_{it} + u_i \tag{1}$$

$$L_i = \ln\left[\frac{p_i}{1-p_i}\right] = \delta_0 + \sum_{i=1}^{9} \delta_i X_{it} + r_k + u_i \tag{2}$$

where, *p* is the probability of '$Y_{t-1} = 1$', Y_{t-1} = Residue burning at field in *t-1* period (*1 = Yes, 0 = No*), X_{it} = Explanatory variables, i = 1-9, k = 1-10, r_k represents unknown clustering [for example, *thana*] effect (i.e., random effect[7]), $r_k \sim N(0, \sigma_r^2)$.

Furthermore, we have also included some additional explanatory measures, such as education of the household head (X_{10t}; Year of schooling) and watching agricultural programs on TV by the household head (X_{11t}; *1=Yes, 0=No*) in the basic logit model and have evaluated their effects on the residue burning decision.

We have evaluated the effects of the dichotomous explanatory variables on the burning decision in terms of the odds of burning (i.e., the odds of land elevation and time interval on the burning decision = $e^{\hat{\beta}}$). For the random-effect logit model, we have calculated an intra-class coefficient (ρ). The coefficient $\hat{\rho}$ indicates the proportion of total variance in the outcome (i.e., straw burning decision) that is attributable to the *thana* level.

In using random-effect regression models, it is often of interest to test whether certain random effects should be included the model. Testing whether a random effect should be included in the model involves the test of whether the variance of that random effect is equal to 0 (zero). We have used a Likelihood Ratio (LR) test in order to check whether *thana* level measure should be included as a random-effect in the model. First, we have fitted a model where the probability of straw burning in the field is the only function of the area (i.e., *thana*), which is accounted for with an area-level random intercept. We have fitted the same model after including each of the exogenous variables as a fixed effect in the model. We then conduct a LR test using the two likelihood values obtained from the two models.

Multicollinearity is a common phenomenon in such research. Therefore, we perform a pair-wise correlation analysis among the explanatory variables in order to check how strongly the variables are correlated. In the case of moderately correlated explanatory variables, as is the case in our study, the impact of multicollinearity is not too severe in estimating the standard error of the estimated βs. In addition, we evaluate the marginal effects (*dY/dX*) for the significant explanatory measures in order to trace the reasons behind the residue burning decision in the field. We use the log likelihood ratio, Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) in order to identify the best model.

4.3 Benefit Estimation

Residue burning is an indubitable fact in the south-west region of Bangladesh since 41 percent of farmers in our study have reported it. Assuming that the farmers are rational, there must be some benefits behind the said behavior of the farmers. The time and cost savings in terms of land preparation and a perceived increase in rice production in the successive seasons are the probable reasons for burning residue in the field. Of these, our study attempts to quantify the 'rice harvesting and residue management' costs of period (*t-1*) and production of

[7] Random-effect regression models (RRMs) have been developed and proposed for analysis of unbalanced clustered data (Laird and Ware, 1982; Longford, 1987). RRMs are useful in the analysis of clustered data because outcomes at the individual level are modeled in terms of both individual- and cluster-level variables while concurrently estimating and adjusting for the amount of intra-class correlation present in the data. Furthermore, these models make no assumption regarding cluster sample size, allowing for a varying number of subjects within each cluster.

period (t) in order to quantify the benefits (partly) of residue burning in the field. Since our data does not permit more than one period lag, it should be noted that the benefit may be realized in a later period as well. Hence, the corresponding main hypothesis for the production function estimation is:

H_3: Residue burning in the field generates production advantages.

In order to address the third hypothesis, we estimate a trans-log production function (equation 3). For this purpose, we incorporate labor (R_{1t}) and fertilizer (R_{2t}) usage in period (t); land elevation (X_{3t} and X_{4t}) and the residue management practice (Y_{t-1}) of period (t-1) as explanatory variables in the production function of period (t). We calculate the outcome measure (Q_t) as production (in maund per acre) in period (t). We measure the labor use (R_{1t}) in man-days per acre and fertilizer use (R_{2t}) in kg per acre for period (t); land elevation (X_{3t} and X_{4t}) as dummy variables with reference to high-elevation land and the residue burning of period (t-1) as a dummy variable (Y_{t-1}) with '*1 for Yes*' and '*0 for No*'. The estimation excludes water usage due to the unavailability of such data in a usable form. We have re-run the equation after omitting the land elevation related variables (X_{3t} and X_{4t}). The variable (Y_{t-1}) considers '100 percent burning' and 'upper part removal and lower part burning' as burning with '*1 for Yes*' and '100 percent removal' and 'upper part removal and lower part incorporation' as non-burning with '*0 for No*'. Therefore, we re-run the translog production function after recoding the variable (Y_{t-1}) based on various residue management practices that are available.

$$LnQ_t = \alpha_0^* + \sum_{j=1}^{2} \alpha_j LnR_{jt} + \frac{1}{2}\sum_{j=1}^{2} \alpha_{jj} (LnR_{jt})^2 + \alpha_{12} LnR_{1t} * LnR_{2t} + \alpha_3 X_{3t} + \alpha_4 X_{4t} + \alpha_5 Y_{t-1} \tag{3}$$

We also run a simple Ordinary Least Square (OLS) regression on per acre production (Q_t; kg per acre) with the same set of explanatory variables (equation 4). We have re-run the equation for the robustness check after omitting the land elevation related variables (X_{3t} and X_{4t}). Similarly, we run an OLS regression on per acre 'rice harvesting and residue management' costs ($RHRMC_{t-1}$; Tk. per acre) at period (t-1) with production (Q_t; kg per acre), labor wage (P_{1t}; Tk. per day), land elevation (X_{3t} and X_{4t}) and the residue management practice (Y_{t-1}) of period (t-1) as explanatory variables (equation 5). We have tried to calculate the 'rice harvesting and residue management' cost per acre ($RHRMC_{t-1}$; in Tk.) for various practices in period (t-1). We consider all sorts of costs, such as cutting, carrying, chopping, gathering, drying, arranging, monitoring, etc., in calculating the 'rice harvesting and residue management' cost. We have re-run the equation 5 after omitting the land elevation dummies (X_{3t} and X_{4t}).

$$Q_t = \mu_0 + \mu_1 R_{1t} + \mu_2 R_{2t} + \mu_3 X_{3t} + \mu_4 X_{4t} + \mu_5 Y_{t-1} \tag{4}$$

$$RHRMC_{t-1} = \theta_0 + \theta_1 Q_t + \theta_2 P_{1t} + \theta_3 X_{3t} + \theta_4 X_{4t} + \theta_5 Y_t \tag{5}$$

$$NR_1 = Q_{1t} - RHRMC_{t-1} \tag{6}$$

$$NR_2 = Q_{1t} - RHRMC_{t-1} - LPOC_t \tag{7}$$

Once we have estimated the production function (equation 3) and run the OLS regressions on the production (equation 4) and 'rice harvesting and residue management' cost (equation 5), we attempt to calculate the benefits of residue burning in the field, if any. Deducting the per acre 'rice harvesting and residue management' cost ($RHRMC_{t-1}$) from per acre gross revenue (Q_{1t}; in Tk.) gives the net gain per acre (NR_1 of equation 6).[8] We then deduct per acre 'land preparation and other costs' ($LPOC_t$; in Tk.) from the net gain per acre of equation 6 (NR_1) to get more precise estimate of net gain per acre (NR_2 of equation 7). A comparison of this net gain data among residue burning and non-burning groups gives some insight into the benefits of residue burning in the field. The corresponding main hypothesis for this purpose is:

H_4: The net gain to the group of farmers who burn rice residue is higher than it is to the group who do not burn rice residue.

[8] Since the 'rice harvesting and residue management' cost data of (t) period is not available and residue management of (t-1) period may affect the gross revenue of (t) period, we deduct the 'rice harvesting and residue management' cost of (t-1) period from gross revenue of (t) period.

5. Results and Discussion

5.1 Descriptive Statistics

The primary occupation of all the respondents in this study is farming. In terms of their profile, they are all household heads in addition to being male and married. Table 2 gives the age distribution and educational qualification of the respondents. As seen in the Table, the age group 36-50 years dominates the sample followed by the age group 51-65 years. While more than one-third of the respondents have 1-5 years of schooling, another approximately one third of the respondents have 6-10 years of schooling. Table 2 also shows that approximately half of the respondents have between 1-3 numbers of cattle. Another one third of the respondents have 4-6 numbers of cattle. While approximately half of the surveyed 300 respondents have no access to electricity, about one-fifth have one or more *pucca* houses, 59 percent have one or more semi-*pucca* houses and 70 percent of the respondents have *kacha* houses.[9] With regard to land ownership, approximately one-fourth of the respondents have either one acre or less while another one-third own 1-2 acres of land with the rest owning more than 2 acres of land (see Table 2). In all, roughly 79 percent of the respondents cultivated five plots or less in 2010. Although almost all the farmers use tractors for land cultivation, with only an insignificant portion (less than 1 percent) of the surveyed farmers using the traditional wooden plough, it is noteworthy that only 9 percent of them own the tractors they use. A similar trend is discernible in the case of irrigation equipment. In addition, we found the surveyed farmers to manually harvest rice and collect the residue from the field (see Table 2).

The residue management behavior of farmers in the south-west region of Bangladesh in the S1 (*Aman*) season varies significantly (see Table 3). The survey[10] results indicate that among the various residue management practices, residue removal from the field dominates followed by field burning of residue. In fact, complete (or 100 percent) field burning of residue is observed only in 3 percent of the surveyed 600 plots. However, we observed 'upper part removal and lower part field burning' in 38 percent of the surveyed 600 plots. If we take into consideration the total acreage of the surveyed 600 plots cultivated by respondents, the burning rate decreases to 34 percent from 41 percent (=3 percent+38 percent). Moreover, the residue management behavior of the surveyed farmers is almost consistent during the 2006-2010 period (see Table 4).

Table 5 describes the variation in residue management behavior of the respondents from different perspectives. Since, in the case of short straw, removal is the dominant practice, residue burning in the field is positively associated with the length of rice straw. While residue which grows less than 4 feet is mostly removed from the field, the frequency of removal is much higher in the case of residue which is less than 2 feet in height. In comparison, more than 70 percent of the respondents burns the rice straw in the field if it is over 4 feet in length. The study finds that the distance of the plot from the homestead of the farmers also influences residue management practice. As Table 5 makes evident, 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-elevation land, residue burning in the field is the dominant trend followed by removal. On the other hand, in the case of high-elevation land, we observe the reverse trend among the surveyed plots. However, in the case of medium-elevation land, both burning and removal practices are observed equally. The Table also shows that an increase in the time-gap between the cultivation of two successive crops increases the frequency of residue removal. This higher likelihood in burning behavior where the time-gap between two crops is short implies that when farmers are in a hurry to cultivate the next crop, they prefer to burn rather than remove the residue.

The open-ended questions in the questionnaire on the reasons behind farmers' behavior identify 'using the residue as cattle feeding' as the main reason for removing from or not burning the whole/lower part of straw in the field (see Table 6). There are also farmers who either remove or do not burn residue for the purpose of selling it. About one-third of the respondents sold the residue derived from one or more plots in 2010. The main reasons behind burning the lower part of residue in the field were the following: (i) to use as fertilizer; (ii) too expensive to remove; and (iii) in order to clear the land quickly (see Table 6). While the higher removal cost was the main reason behind not removing the residue from the field, approximately half of the respondents also thought that residue burning in the field generated fertilizer in the field for the successive seasons (see Table 6).

9 The total exceeds 100 percent because we allow multiple answers in the question on housing-patterns.

10 The survey covers 600 plots taking the two biggest plots of each sample households irrespective of residue burning practice or location of the plots.

5.2 Why Do Farmers Burn Residue in the Field?

Table 7 (Model 1) reports the estimation result of the basic logit model of equation 1. It shows that all the regression coefficients have the expected sign. The statistically significant variables are: X_{2t} (length of rice straw - in feet); X_{3t} (low-elevation land - 4+ months of water logging/year); X_{5t} (distance of the rice field from the farmer's homestead - in kilometer); and X_{9t} (residue price - in Thousand Tk./acre). The results indicate that straw length, low-elevation land and distance of the plot positively influence the residue burning decision of the farmers while the residue price negatively influences the residue burning decision. A pair-wise correlation analysis indicates an absence of any severe multicollinearity among the explanatory variables of the model.

Since education and access to media might influence the residue burning behavior of the farmers, Model 2 of Table 7 attempts to incorporate the education level of the household head (X_{10t}) and watching agricultural programs on TV by the household head (X_{11t}) as explanatory variables in the basic logit model framework. The results remain almost the same after incorporating these two explanatory variables.

Table 7 (Model 3) illustrates the random-effect logit regression results. All the regression coefficients of the model have the expected sign. The fixed-effect logit regression results (see Model 4 of Table 7) and linear probability model results (see Model 5 of Table 7) almost coincide with the findings of the random-effect logit regression results, which indicate the robustness of the study findings. However, the Log likelihood ratio test, Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) demonstrate that the random-effect logit model is a better fit in the current data set (see Table 7). Moreover, according to Kalbflesisch et al. (1970), the fixed-effect approach (i.e., the dummy variable approach) may suffer severe 'incidental parameters bias' for the logit regression model. Therefore, the result obtained from the random-effect logit model seems to be more reliable than the other models considered in this study.

The odd ratio of residue burning in low-elevation land is 4.18 indicating that the odds of residue burning in low-elevation land is 318 percent higher in comparison with the odds of residue burning at high-elevation land after controlling for the effects of all the other variables considered in the random-effect logit model.

The estimated intra-class coefficient (ρ) for the *thana* level information in the random-effect logit model is 0.38, which suggests that approximately 38 percent of the variability in the residue burning decision can be explained by the *thana* level measures. The remaining 62 percent variability in the residue burning decision can be explained by farm-level measures. We used a Likelihood Ratio (LR) test to evaluate the significance of the intra-class correlation. The chi-square value for the log-likelihood ratio test statistic[11] is 83.90; hence the intra-class correlation is statistically different from zero. That is, it is important to control for the variability in residue burning due to *thana* level measures (i.e., taking *thana* as a random-effect) in evaluating the significance of the farm-level measures.

Since the random-effect logit model is a better fit in the current data set, we report the marginal effects from this model (see Table 8). The marginal effects for X_{2t} (straw length), X_{3t} (low-elevation land), X_{5t} (distance of the plot from home) and X_{9t} (residue price) are statistically significant. Results indicate that an increase in straw length by 1 foot increases the probability of burning rice residue by 0.16 percent; and an increase in the distance of the plot from the homestead by 1 km increases the probability of burning rice residue by 0.12 percent. Compared with farmers cultivating high-elevation land, farmers cultivating low-elevation land are 0.34 percent more likely to burn rice residue. Moreover, an increase in straw price by 1 thousand Tk. per acre decreases the probability of burning rice residue by 0.03 percent.

5.3 What Are the Benefits to Farmers from Burning Residue in the Field?

The translog production function estimation (on a per-acre basis) results indicate that residue burning (Y_{t-1}) at period (*t-1*) has a positive impact on production Q_t) at period (*t*) although the impact is not significant (see Model 1, Table 9). A pair-wise correlation analysis between residue burning (Y_{t-1}) and low-elevation land (X_{3t}) reveals only a moderate, though statistically significant, correlation (*r=0.21*) between these two variables. However, the trans-log production function (on a per-acre basis) estimation results remain almost the same even after dropping the

[11] (–2*[–295.95 – (–254.70)])=83.90

land-elevation-related variables (see Model 2, Table 9). However, while experimenting for the purpose of using a Cobb-Douglas function, we found the squared and cross terms of the trans-log production function (on a per-acre basis) to be jointly statistically significant (*p=0.0001*), which advocates the use and interpretation of the trans-log function instead of the Cobb-Douglas production function. The plot-wise (instead of on a per-acre basis) trans-log production function estimation also provides similar results which indicate the robustness of the findings. All of the elasticity coefficients derived from the trans-log production function (on a per-acre basis) for the considered inputs have the expected sign. The elasticity (ER_i)[12] for labor and fertilizer are 0.13 and 0.70 respectively. The calculated marginal productivity (MPR_i)[13] (at mean) for labor and fertilizer are 0.2373 and 0.2377 respectively which indicates that one unit increase in labor (one man-day/acre) and fertilizer (one kg/acre) increases the rice production by 8.86 and 8.87kg/acre respectively.

Re-running the trans-log production function (on a per-acre basis) with two dummy variables for the three main residue management practices-i.e., Burning ($Y_{1(t-1)}$), Removal ($Y_{2(t-1)}$) and Incorporation (as reference) of (*t-1*) period while keeping all other dependent and explanatory variables of equation 3 also finds that residue burning at period (*t-1*) has a positive impact on the production (Q_t) at period (*t*) and that the impact is significant (see Models 3 and 4, Table 9). Alternatively, we recode the residue management practices into four types: 100 percent Burning ($Y_{11(t-1)}$); 100 percent Removal ($Y_{22(t-1)}$); 'upper part removal and lower part burning' ($Y_{44(t-1)}$); and 'upper part removal and lower part incorporation' (as reference) and re-run the trans-log production function (on a per-acre basis) with three dummy variables for the four residue management practices of (*t-1*) period while keeping all other dependent and explanatory variables of equation 3. The results indicate that both 100 percent residue burning at period (*t-1*) and 'upper part removal and lower part burning' at (*t-1*) period have a positive impact on the production at period (*t*) and that the impact is significant (see Models 5 and 6, Table 9).

A simple OLS regression of labor use (R_{1t}; man-days per acre); fertilizer use (R_{2t}; kg per acre); land elevation (X_{3t} and X_{4t}); and the residue burning practice (Y_{t-1}) of period (*t-1*) on per acre production (Q_t; kg per acre) at period (*t*) indicates that residue burning at period (*t-1*) has a positive impact on production at period (*t*) though the impact is not significant (see Model 1, Table 10). The regression result remains almost similar if it is re-run after omitting the land elevation variables (see Model 2, Table 10).

Another OLS regression of the production (Q_t; kg per acre); labor wage (P_{1t}; Tk. per day); land elevation (X_{3t} and X_{4t}); and the residue burning practice (Y_{t-1}) of period (*t-1*) on per acre 'rice harvesting and residue management' cost ($RHRMC_{t-1}$; Tk. per acre) at period (*t-1*) indicates that residue burning helps to reduce the 'rice harvesting and residue management cost' and the impact is significant (see Model 3, Table 10). A similar result is found from re-running the regression after omitting the land elevation variables (see Model 4, Table 10).

The production function estimation results, OLS regression results, literature survey findings and farmers' opinions on the impact of residue burning signal that residue burning in the field offers some advantages to farmers in terms of reducing production cost and increasing production volume. The next step is to quantify these advantages or benefits.

We identify at least two probable sources of benefits: (i) 'rice harvesting and residue management' cost in period (*t-1*) and (ii) production in period (*t*). For this study, we calculated the 'rice harvesting and residue management' cost ($RHRMC_{t-1}$; in Tk. per acre) for period (*t-1*). We also calculated the production benefits (Q_{1t}; in Tk. per acre) using the production volume (Q_t; in maund per acre) and price data of rice in period (*t*). The difference between per-acre gross revenue and per-acre 'rice harvesting and residue management' cost is the net gain per-acre (NR_1; in Tk. per acre) after controlling for all other related variables. We conducted a two-sample mean difference test on the per-acre net gain data between the residue burning and non-burning groups. The mean difference between the benefits (i.e., net gains) of the residue burning and non-burning groups is Tk. 3,240 (USD 43) per acre, which is statistically significant at the 10 percent level (see Table 11) for one-tailed test. Next we deduct per acre 'land preparation and other costs' ($LPOC_t$; in Tk. per acre) from the calculated net gain per acre (NR_1; in Tk. per acre) to get a better estimate of net gain per acre (NR_2; in Tk. per acre). The mean difference between the benefits (i.e., net gains) of

12 The formula for calculating the elasticity of the i^th input (Tchale and Sauer, 2007) is: $ER_i = \frac{\partial LnQ}{\partial LnR_i} = \alpha_i + \sum_{j=1}^{2} \alpha_{ij} LnR_j$ (8)

13 The formula for calculating the marginal productivity of the i^th input (Tchale and Sauer, 2007) is: $MPR_i = ER_i * \frac{Q}{R_i}$ (9)

the residue burning and non-burning groups is Tk. 3,353 (USD 45) per acre, which is also statistically significant at the 12 percent level for one-tailed test.

In comparing mean values related to farmers who burn with those who don't burn, there are two reasons why the t-tests may not have been significant at the 5 percent level. It could be that the sample size estimation for this survey was not based on a statistical power analysis, and hence the included household sample size may be smaller than the required sample size for the test comparisons to be statistically significant. Alternatively, the clustered design effects were not included in estimating the standard error of the test statistics, and hence the estimated standard errors may not be precisely correct. However, the lager mean differences in net benefits in per-acre net gain between burning and non-burning groups along with significances at ≤12 percent level indicate that the farmers who are burning residue in the field are getting higher benefits from their residue burning practices.

5.4 Discussion

There is no national data that presents the amount of rice residue burnt in the field either for all of Bangladesh or for the south-west region of the country. BBS (2011) statistics indicate that the eleven districts of the region cultivated the local *Aman* variety in 0.06 million acres of land in the year 2008 which is 50 percent of the total *Aman*-cultivated land in the region. If we take into consideration, along with all other related assumptions, the fact that the percentage of residue burnt was 34 percent and that average rice production was 1.37 mt/acre (Field survey, 2011), the amount of rice residue burnt in the region in 2008 is approximately 0.21 million mt. Since a total of 12.21 million mt of *Aman* rice was produced in 1.41 million acre land of Bangladesh in the year 2010, it is possible, using the same method, to estimate that the country burnt 3.14 million mt of rice residue that year. However, this can only be a rough estimate since residue burning frequency varies significantly across the different regions of the country. Further investigations are therefore necessary to arrive at more precise estimates.

The findings of this study indicate that rice residue burning in the field generates benefits for the farmers who are engaged in this practice. On average, they earn a Tk. 3,240-3,353/acre (USD 43-45/acre) equivalent benefit from this activity. Moreover, the literature indicates that residue burning in the field has long-term production advantages (Surekha et al., 2003). Therefore, the benefit in the long run might be more than the calculated Tk. 3,240-3,353/acre (USD 43-45/acre) benefit.

We asked the farmers about their willingness to accept compensation[14] for giving up the residue burning practice. According to the field survey data, the average compensation demanded by the currently residue burning farmers is Tk. 3,355/acre (USD 45/acre) for giving up the behavior. We note that this 'stated' amount is very close to the number obtained by looking at actual net benefits from revealed preferences for burning (Tk. 3,240-3,353/acre or USD 43-45/acre). The claim is higher (at Tk. 3,962/acre or USD 53/acre) for farmers who do not burn residue in surveyed plots but burn the residue in other plots cultivated by them, which are comparatively of low-elevation. A higher claim for the lower quality straw derived from comparatively low-elevation land indicates greater likelihood of burning, which supports the assumption that comparatively lower quality straw is burnt in the field.

Since this study attempts to derive a marginal cost curve for managing rice residue alternatively (see Figure 1) in addition to inquiring into reasons why farmers burn residue, it also considers the compensation demanded by farmers for giving up residue burning behavior for the purpose of deriving the marginal cost curve. The figure considers the compensation[15] demanded by the farmers for giving up field burning of residue as the marginal cost of residue burning in the field and illustrates the survey responses in ascending order for getting the marginal cost curve. The upward slopping figure indicates the farmers' willingness to accept higher compensation for not burning the residue of worse quality or of distanced plots.

The findings of the study clearly indicate that residue burning in the field generates some benefits. For that very reason, the farmers might not stop the residue burning practice voluntarily without some form of compensation. Since open burning of crop residue in the field indubitably causes gaseous and particulate emissions that carry

14 The corresponding question was: What is the minimum amount of compensation (Tk./acre) do you expect to give up the practice of residue burning in the field?

15 Thousand Tk. per acre

negative consequences to the environment and human health, the question for policy-makers might be: What measures can be introduced to deal with the rice residue burning problem in this study area or in other regions of Bangladesh where such residue burning practice is prevalent?

An important aspect needing attention for the purpose of addressing the residue burning problem might be the choice of rice variety. Although varieties with long-straw are usually grown in low-lying land so that the crops can survive instances of flooding, our survey data found only a moderate correlation (r = 0.19) between straw length and low-elevation land. Instead, the field survey found long-straw varieties to be grown in medium- and high-elevation lands as well. Therefore, subsidies for the purchase of new varieties of seeds and/or education can be used to persuade farmers to move to short-straw varieties on high/medium-elevation lands where flooding is not an issue.

Our findings suggest that farmers forgo benefits of about USD 43-45/acre if they stop burning. We find that the residue of around 0.48 million acre *Aman* cultivated land is burnt in Bangladesh in 2010. Considering the estimated willingness to accept for giving up residue burning, famers would need to be subsidized approximately Tk. 1,616 million (USD 2.10 million) per year[16] for avoiding residue burning in Bangladesh.

The study also highlights the need for more research and development efforts in order to address the rice residue burning problem. We suggest that policy makers promote efforts to develop rice varieties with shorter straw. Not only does this study find a positive relationship between straw length and residue burning in the field, it also finds a relationship between rice variety and residue burning in the field. The *Jabra* and *Balam* varieties have a higher frequency of burning residue in the field in comparison to *IRRI* and *Sarna* varieties (see Table 12). The Table also shows that the average straw length of the *Jabra* and *Balam* varieties are higher than that of *IRRI* and *Sarna* varieties. Since the field data finds no significant difference in productivity for the four rice varieties (see Table 12), an attempt should be made to persuade farmers to avoid the use of *Jabra* and *Balam* varieties through educating farmers on the comparatively high negative impacts of using these varieties.

The results indicate that the bigger the difference between planting and harvesting time, the higher the frequency of residue burning in the field (see Figure 2). A longer time between rice planting and harvesting means less time for land preparation given that farmers have to plant the next crop by the given date. Agricultural researchers and extension services could put more effort into developing new rice varieties or modifying existing varieties in order to come up with ones that have a shorter growth period.

The field-level data also demonstrate that manual collection of both rice and residue is prevalent in the study area. It is possible that new technologies could lead to better management of rice residue. For example, Gupta (2012) finds that the use of the Happy Seeder[17] is helping reduce residue burning in India. However, we have to keep in mind that the solution to the issues underlined above depends on careful attention to rice productivity, geographical features, water-logging conditions and salinity issues of the area under consideration since they are of paramount importance in the decisions farmers make on issues such as crop residue.

6. Conclusions and Policy Recommendations

This study identifies the factors that determine rice residue burning in the south-west region of Bangladesh and the options available for farmers to manage residue. We find that straw length, low-elevation land and distance to the plot from the farmer's homestead positively and significantly influence the rice residue burning decision in the field. Residue price negatively influences the residue burning decision of farmers. The time gap between two successive seasons, use of straw, farm size, and age of farmers are among other factors influencing the rice residue burning decision.

16 This subsidy would amount to about 4 percent of the total subsidy provided for fertilizer and other agricultural inputs in year 2010 for the country. According to GOB (2011), Bangladesh provided about 60 million USD as subsidy for fertilizer and other agricultural inputs in year 2010.

17 A type of tractor that cuts and lifts the rice straw, sows wheat into the bare soil, and deposits the straw over the sown area as mulch. It precludes the burning of rice residue.

By estimating a production function, we show that residue burning enhances the productivity of the field in the successive seasons. Residue burning behavior also reduces the 'rice harvesting and residue management' cost. Farmers in the burning group enjoy a yearly net benefit of Tk. 3,240-3,353/acre (or USD 43-45/acre) on average from residue burning in the field relative to farmers in the non-burning group.[18] Their willingness to accept compensation for giving up the practice of rice residue burning is Tk. 3,355/acre (or USD 45/acre) which is far less[19] than the average market price of residue (at Tk. 6,746/acre or USD 90/acre). The sold residue is mostly used for cattle feeding. We also found the sold residue to be of better quality and are derived from shorter rice straw, collected from the nearer rice fields, and from favorable rice varieties such as *IRRI* and *Sarna*. On the other hand, we found farmers to burn the lower quality residue derived from the longer straw which grows in low-elevation land because this lower quality straw does not have a high demand. The above scenario indicates that certain policy interventions might be needed to persuade farmers to give up the residue burning practice.

We have outlined several policy measures to address the problem of residue burning in the field. One approach might be to work on reducing straw length so that field burning of residue becomes unnecessary. Subsidies for the purchase of new varieties of seeds and/or education are other measures that can be used to persuade farmers to move to short-straw varieties on high/medium-elevation lands. Since such a policy intervention might not work for low-elevation lands as the farming conditions on those lands require long straw varieties, an alternative approach might be to switch from residue burning to incorporation. Since incorporation is better from the view-point of soil fertility, extension efforts in this direction, as well as technological innovations to make incorporation more easy, should be explored with regard to policy intervention. However, the field survey found the practice of straw incorporation to be very limited at only 5 percent of the surveyed 600 plots. Since the study did not find any strong correlation between incorporation and straw length, land elevation, and rice variety, there is significant scope for encouraging farmers to switch to incorporation.

Research and development can play a noteworthy role in addressing the problem under study. Since this study finds shorter straw length, shorter time period between the planting and harvesting time, and the cultivation of specific rice varieties such as *IRRI* and *Sarna* to help in reducing residue burning in the field, more research can be done on reducing straw length and time-period between planting and harvesting, rice variety development, and residue collection methods in order to address the residue management issue. However, such research must factor in rice productivity, geographical features, the water-logging condition, salinity and other issues related to rice-farming in the south-west region of Bangladesh.

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[18] This benefit accrue because the burning group enjoys 9 percent production advantage, 10 percent 'rice harvesting and residue management cost' advantage and concerned other advantages derived from land preparation and other costs on average over the non-burning group (see Table 11).

[19] The market price of the sold residue is higher as only the better quality straw is sold. On the other hand, the lower quality straw is burnt in the field and the respondents express the willingness to accept compensation for that lower quality straw. It is difficult to collect and sell that lower quality straw. For the very reason, the willingness to accept is lower than the price of better quality straw.

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Tables

Table 1: Variable Description

Symbol	Variable Name	Variable Description	N	Mean	SD	Min.	Max.
$Y_{1(t-1)}$ (= Y_{t-1})	Burning Dummy (or, Residue Burning Dummy; Non-Burning is the Reference)	Incorporation is the reference for creating dummies: $Y_{1(t-1)}$ and $Y_{2(t-1)}$; 1 = Burning, 0 = Else (or, Residue burning decision at field in *t-1* period; 1 = Yes, 0 = No)	600	0.41	0.49	0	1
$Y_{2(t-1)}$	Removal Dummy	Incorporation is the reference for creating dummies: $Y_{1(t-1)}$ and $Y_{2(t-1)}$; 1 = Removal, 0 = Else	600	0.55	0.50	0	1
$Y_{11(t-1)}$	100 percent Burning Dummy	'Upper part removal and lower part incorporation' is the reference for creating dummies: $Y_{11(t-1)}$, $Y_{22(t-1)}$, and $Y_{44(t-1)}$; 1 = 100 percent Burning, 0 = Else	600	0.03	0.17	0	1
$Y_{22(t-1)}$	100 percent Removal Dummy	'Upper part removal and lower part incorporation' is the reference for creating dummies: $Y_{11(t-1)}$, $Y_{22(t-1)}$, and $Y_{44(t-1)}$; 1 = 100 percent Removal, 0 = Else	600	0.55	0.50	0	1
$Y_{44(t-1)}$	'Upper Part Removal and Lower Part Burning' Dummy	'Upper part removal and lower part incorporation' is the reference for creating dummies: $Y_{11(t-1)}$, $Y_{22(t-1)}$, and $Y_{44(t-1)}$; 1 = 'Upper part removal and lower part burning', 0 = Else	600	0.38	0.49	0	1
X_{1t}	Time Interval	Time interval between two successive cultivations on the same land; 1 = More than or equal to one month, 0 = Less than one month	595	0.82	0.38	0	1
X_{2t}	Straw Length	Length of rice straw (in feet)	600	3.63	1.14	1.5	8.5
X_{3t}	Low-elevation Land	High-elevation land (less than 2 months of water logging/year) is the reference for creating dummies (X_3 & X_4) of land elevation; 1 = Low-elevation land (4^+ months of water logging/year), 0 = Else	600	0.16	0.36	0	1
X_{4t}	Medium-elevation Land	High-elevation (less than 2 months of water logging/year) is the reference for creating dummies (X_3 & X_4) of land elevation; 1 = Medium-elevation land (2-4 months of water logging/year), 0 = Else	600	0.50	0.50	0	1
X_{5t}	Distance	Distance of field from farmer's homestead (in kilometer)	600	0.69	0.87	0.001	15
X_{6t}	Farm Size	Farm size (owned land in acre)	600	2.14	1.77	0.06	12.75
X_{7t}	Cattle Ownership	No. of cattle owned (for per acre of land)	600	3.32	5.31	0	50
X_{8t}	Farmer's Age	Age of the farmer (in years)	600	47.22	10.96	25	90
X_{9t}	Residue Price	Residue price (Thousand Tk./acre)	600	6.75	3.76	2.71	17.25
X_{10t}	Education	Year of schooling of the household head	600	5.40	3.72	0	18
X_{11t}	Watching TV	Watching agricultural program on TV; 1 = Yes, 0 = No	600	0.45	0.50	0	1
Q_t	Production	Production per acre in a plot in (*t*) period (in maund)	597	45.44	25.10	2	166.67
Q_{1t}	Production (Tk.)	Production in Tk. per acre in a plot in (*t*) period	596	22,512	16,848	80	97,500
R_{1t}	Labor Use	Use of labor per acre in (*t*) period (man-day)	592	24.21	24.74	0.08	280
R_{2t}	Fertilizer Use	Use of fertilizer per acre in (*t*) period (in kg)	515	133.42	99.69	8	607.14
P_{1t}	Labor Wage	Labor wage (Tk. per day)	600	226	59	100	400
$RHRMC_{t-1}$	Rice Harvesting and Residue Management Cost	Rice harvesting and residue management cost in a plot in (*t-1*) period (Tk. per acre)	599	13,561	12,552	236	89,600
$LPOC_t$	Land Preparation and Other Costs	Land preparation and other costs in a plot in (*t*) period (Tk. per acre)	597	15,651	8,192	1,020	41,988

Table 2: 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; Multiple answer)	*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	236	79
	6 – 10	57	19
	10+	7	2
	Total	**300**	**100**
Cultivation Equipment	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

Table 3: Residue Management Practices in the Surveyed Plots

Residue Management Practice	Frequency	Percent (%)
Burning	244	41
No Burning	356	59
Total	**600**	**100**

N.B.: Burning includes – (a) 100 percent field burning and (b) Upper part removal and lower part field burning.
No burning includes – (a) 100 percent removal from the field and (b) Upper part removal and lower part field incorporation.

Table 4: Residue Management Behavior over the Time Period

Residue Management Behavior	Percent of the Respondent				
Year	**2006**	**2007**	**2008**	**2009**	**2010**
100 percent Field Burning	3	3	3	3	3
100 percent Field Removal	53	54	55	54	53
100 percent Field Incorporation	1	1	0	0	0
Upper Part Removal and Lower Part Field Burning	37	37	39	39	39
Upper Part Removal and Lower Part Field Incorporation	5	4	3	4	5
Missing	1	1	0	0	0
Total	**100**	**100**	**100**	**100**	**100**
Burning	59	59	58	58	58
No burning	40	40	41	42	42
Missing	1	1	1	0	0
Total	**100**	**100**	**100**	**100**	**100**

N.B.: Burning includes – (a) 100 percent field burning and (b) Upper part removal and lower part field burning.
No burning includes – (a) 100 percent removal from the field and (b) Upper part removal and lower part field incorporation.

Table 5: Residue Management Practices vs. Various Factors

Criteria	Category	BB	RR	RB	RI	Total
				(in %)		
Length of the Residue (Feet)	0 – 2.0	3	92	5	0	100
	2.1 – 4.0	2	63	31	4	100
	4.1 – 6.0	4	16	71	9	100
	6+	18	12	70	0	100
Distance of the Plot from Homestead (km)	0 – 0.5	3	64	30	3	100
	0.5 – 1.0	2	58	36	4	100
	1.1 – 2.0	5	38	51	6	100
	2+	0	33	48	19	100
Land Elevation	Low land	3	29	61	7	100
	Medium	3	49	42	6	100
	High	2	74	22	2	100
Time Gap between S1 and S2 Seasons (Month)	0 months	4	43	48	5	100
	0.01 – 1.00	2	57	38	3	100
	1.01 – 3.00	3	55	34	8	100
	3+ months	17	83	0	0	100

N.B.: **'BB'** refers to 100 percent field burning;
'RR' refers to 100 percent 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.
Total may not add up to 100 due to rounding error.

Table 6: Reasons behind Various Residue Management Practices

Topics \ Reasons	Percent of the Respondent				
	Fertilizer	To Save Time	Expensive to Remove	Others	All
Why do you burn the whole residue? [N=17]	47	29	24	00	**100**
Why do you burn the lower part of the residue? [N=230]	51	04	20	25	**100**
Why do you incorporate the lower part of residue? [N=25]	68	00	00	32	**100**
Why do you not remove the whole residue? [N=164]	02	00	48	50	**100**
Topics \ Reasons	**Cattle Feeding**	**To Sell**	**No Idea**	**Others**	**All**
Why do you not burn the whole residue? [N=576]	64	16	20	00	**100**
Why do you not burn the lower part of the residue? [N=280]	64	20	16	00	**100**
Why do you not incorporate the lower part of the residue? [N=500]	17	19	20	44	**100**
Why do you remove the whole residue? [N=314]	89	11	00	00	**100**
Why do you remove the upper part of the residue? [N=278]	99	01	00	00	**100**

Table 7: Reasons behind Residue Burning in the Field

Symbol	Variable Name	(1) Logit Model	(2) Logit Model (Extended)	(3) Random-Effect Logit Model	(4) Fixed-Effect Logit Model	(5) Linear Probability Model
X_{1t}	Time Interval	-0.36	-0.33	-0.51	-0.52	-0.07
		(0.28)	(0.29)	(0.33)	(0.33)	(0.05)
X_{2t}	Straw Length	0.92***	0.93***	0.68***	0.63***	0.16***
		(0.12)	(0.12)	(0.14)	(0.14)	(0.02)
X_{3t}	Low Land	0.73**	0.72**	1.43***	1.49***	0.16***
		(0.33)	(0.33)	(0.39)	(0.40)	(0.06)
X_{4t}	Medium Land	0.20	0.20	0.27	0.28	0.05
		(0.24)	(0.24)	(0.28)	(0.28)	(0.04)
X_{5t}	Distance	0.29**	0.29**	0.50***	0.52***	0.05**
		(0.14)	(0.14)	(0.19)	(0.19)	(0.02)
X_{6t}	Farm Size	0.04	0.03	0.12	0.13	0.01
		(0.06)	(0.07)	(0.09)	(0.09)	(0.01)
X_{7t}	Cattle Ownership	0.00	0.00	-0.01	-0.01	-0.00
		(0.02)	(0.02)	(0.02)	(0.02)	(0.00)
X_{8t}	Farmer's Age	-0.00	-0.00	-0.00	-0.00	-0.00
		(0.01)	(0.01)	(0.01)	(0.01)	(0.00)
X_{9t}	Residue Price	-0.19***	-0.19***	-0.12**	-0.10	-0.03***
		(0.04)	(0.04)	(0.06)	(0.06)	(0.01)
X_{10t}	Education	-	0.02	-	-	-
		-	(0.03)	-	-	-
X_{11t}	Watching TV	-	0.02	-	-	-
		-	(0.21)	-	-	-
Constant		-2.62***	-2.84***	-2.50***	-	0.03
		(0.72)	(0.82)	(0.96)	-	(0.11)
Observations		595	595	595	595	595
Number of Group (*thana*)		-	-	10	10	-
Log Likelihood		-295.95	-295.77	-254.70	-217.34	-
Intra Class Correlation (rho)		-	-	0.38	-	-
R^2		-	-	-	-	0.31
Pseudo R^2		0.27	0.27	-	-	-
AIC		611.90	615.55	531.39	552.67	645.17
BIC		655.79	668.21	579.67	592.17	689.05

Dependent Variable: Y_{t-1} - Residue burning decision at field in (*t-1*) period; *1 = Yes, 0 = No*

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

Table 8: Marginal Effect and Odd Ratio of Random Effect Logit Model

Symbol	Variable Name	Random-Effect Logit Model
X_{1t}	Time Interval	-0.12
		(0.08)
X_{2t}	Straw Length	0.16***
		(0.04)
X_{3t}	Low Land	0.34***
		(0.09)
X_{4t}	Medium Land	0.06
		(0.07)
X_{5t}	Distance	0.12**
		(0.05)
X_{6t}	Farm Size	0.03
		(0.02)
X_{7t}	Cattle Ownership	0.00
		(0.01)
X_{8t}	Farmer's Age	0.00
		(0.00)
X_{9t}	Residue Price	-0.03**
		(0.01)
Observations		595
Number of Group (*thana*)		10
Intra Class Correlation (rho)		0.38
Odd Ratio for X_{1t}: 0.60, for X_{3t}: 4.18***, for X_{4t}: 1.31		

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

Table 9: Trans-log Production Function Estimation

Symbol	Variable Name	(1) **$\log Q_t$ (per-acre)**	(2) **$\log Q_t$ (per-acre)**	(3) **$\log Q_t$ (per-acre)**	(4) **$\log Q_t$ (per-acre)**	(5) **$\log Q_t$ (per-acre)**	(6) **$\log Q_t$ (per-acre)**
LnR_{1t}	Labor	0.16	0.16	0.16	0.15	0.15	0.14
		(0.11)	(0.11)	(0.11)	(0.11)	(0.11)	(0.11)
LnR_{2t}	Fertilizer	1.05^{***}	1.06^{***}	1.05^{***}	1.07^{***}	1.01^{***}	1.03^{***}
		(0.22)	(0.22)	(0.22)	(0.22)	(0.22)	(0.22)
LnR_{11t}	Labor * Labor	0.07^{***}	0.07^{***}	0.07^{***}	0.07^{***}	0.07^{***}	0.07^{***}
		(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
LnR_{22t}	Fertilizer * Fertilizer	-0.12^{**}	-0.12^{**}	-0.12^{**}	-0.13^{**}	-0.11^{**}	-0.12^{**}
		(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)
LnR_{12t}	Labor * Fertilizer	-0.06^{***}	-0.06^{***}	-0.06^{***}	-0.06^{***}	-0.06^{***}	-0.05^{**}
		(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
X_{3t}	Low Land Dummy against High Land as Reference	-0.04	–	-0.02	-	-0.01	–
		(0.07)	–	(0.07)	-	(0.07)	–
X_{4t}	Medium Land Dummy against High Land as Reference	0.06	–	0.08	-	0.09^{*}	–
		(0.05)	–	(0.05)	-	(0.05)	–
Y_{t-1}	Burning Dummy against Non-burning as Reference	0.002	0.001	-	-	-	–
		(0.05)	(0.05)	-	-	-	–
$Y_{1(t-1)}$	Burning Dummy against Incorporation as Reference	–	–	0.28^{**}	0.26^{**}	-	–
		–	–	(0.13)	(0.13)	-	–
$Y_{2(t-1)}$	Removal Dummy against Incorporation as Reference	–	–	0.30^{**}	0.28^{**}	-	–
		–	–	(0.13)	(0.12)	-	–
$Y_{11(t-1)}$	100 percent Burning Dummy against 'Upper Part Removal and Lower Part Incorporation' as Reference	–	–	–	–	0.63^{***}	0.61^{***}
		–	–	–	–	(0.18)	(0.18)
$Y_{22(t-1)}$	100 percent Removal Dummy against 'Upper Part Removal and Lower Part Incorporation' as Reference	–	–	–	–	0.31^{**}	0.28^{**}
		–	–	–	–	(0.13)	(0.12)
$Y_{44(t-1)}$	'Upper Part Removal and Lower Part Burning' Dummy against 'Upper Part Removal and Lower Part Incorporation' as Reference	–	–	–	–	0.25^{**}	0.24^{*}
		–	–	–	–	(0.13)	(0.13)
Constant		0.21	0.22	-0.08	-0.04	0.02	0.05
		(0.51)	(0.51)	(0.53)	(0.53)	(0.52)	(0.52)
Observations		507	507	507	507	507	507
R^2		0.34	0.33	0.35	0.34	0.35	0.35

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

Table 10: OLS Regression on Production and 'Rice Harvesting and Residue Management' Cost

Symbol	Variable Name	Production in (*t*) period (Maund per-acre)		'Rice Harvesting and Residue Management' Cost (Tk. per-acre)	
		(1)	(2)	(3)	(4)
		Q_t	Q_t	$RHRMC_{t-1}$	$RHRMC_{t-1}$
R_{1t}	Labor	0.07^{**}	0.07^{**}	-	-
		(0.03)	(0.03)	-	-
R_{2t}	Fertilizer	0.12^{***}	0.12^{***}	-	-
		(0.01)	(0.01)	-	-
Q_t	Production	-	-	98.86^{***}	98.81^{***}
		-	-	(20.12)	(20.09)
P_{1t}	Labor Wage	-	-	24.23^{***}	24.37^{***}
		-	-	(8.99)	(8.96)
X_{3t}	Low Land	-2.36	-	929.93	-
		(2.71)	-	(1,594.32)	-
X_{4t}	Medium Land	1.07	-	-469.86	-
		(1.93)	-	(1,135.38)	-
Y_{t-1}	Residue Burning	0.23	0.02	$-2,063.94^{*}$	$-1,964.15^{*}$
		(1.81)	(1.75)	(1,080.10)	(1,041.30)
Constant		32.11^{***}	32.45^{***}	$4,487.09^{*}$	$4,328.10^{*}$
		(2.05)	(1.75)	(2,317.26)	(2,255.58)
Observations		507	507	596	596
R^2		0.28	0.28	0.05	0.05

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

Table 11: Net Benefit of Residue Burning in the Field

Benefits	Burning Group	Non-Burning Group	Mean Difference	t statistics	Advantage of Burning Group over Non-Burning Group (%)
(A) Production in (*t*) period (Tk./acre)	23,659	21,722	1,937	-1.38	8.92
(B) 'Harvesting and Residue Management' Cost in (*t-1*) period (Tk./acre)	12,727	14,134	-1,407	1.35	9.95
NR_1 (=A-B) Mean net benefits from two sources* together (Tk./acre)	10,884	7,644	**3,240**	-1.58	42.39
(C) 'Land Preparation and Other' Cost in (*t*) period (Tk./acre)	15,526	15,738	-213	0.31	1.35
(B+C) 'Harvesting and Residue Management' Cost in *(t-1)* period and 'Land Preparation and Other' Cost in (*t*) period (Tk./acre)	28,253	29,767	-1,514	1.07	5.09
NR_2 {=A-(B+C)} Mean net benefits from three sources* together (Tk./acre)	-4,667	-8,020	**3,353**	-1.54	41.81
Average compensation demanded by the currently residue burning farmers (Tk./acre)			**3,355**	-	

*Sources: **(A)** - Production in (t) period, **(B)** - 'Harvesting and Residue Management' Cost in (t-1) period, and **(C)** - 'Land Preparation and Other' Cost in (t) period (Tk./acre).

Table 12: Rice Variety vs. Residue Burning, Straw Length and Productivity

Rice Variety	*IRRI*	***Sarna***	***Balam***	***Jabra***	**Others**	**All**
Frequency	209	115	56	51	169	600
Burning (%)	22	21	59	86	58	41
Non-Burning (%)	78	79	41	14	42	59
All (%)	**100**	**100**	**100**	**100**	**100**	**100**
Average straw length (feet)	**3.07**	**3.36**	**4.03**	**5.03**	**3.96**	**3.63**
Productivity (Maund/Acre)	**20**	**24**	**21**	**21**	**19**	**21**

Figures

Figure 1: Marginal Cost Curve for Alternative Management of Rice Residue

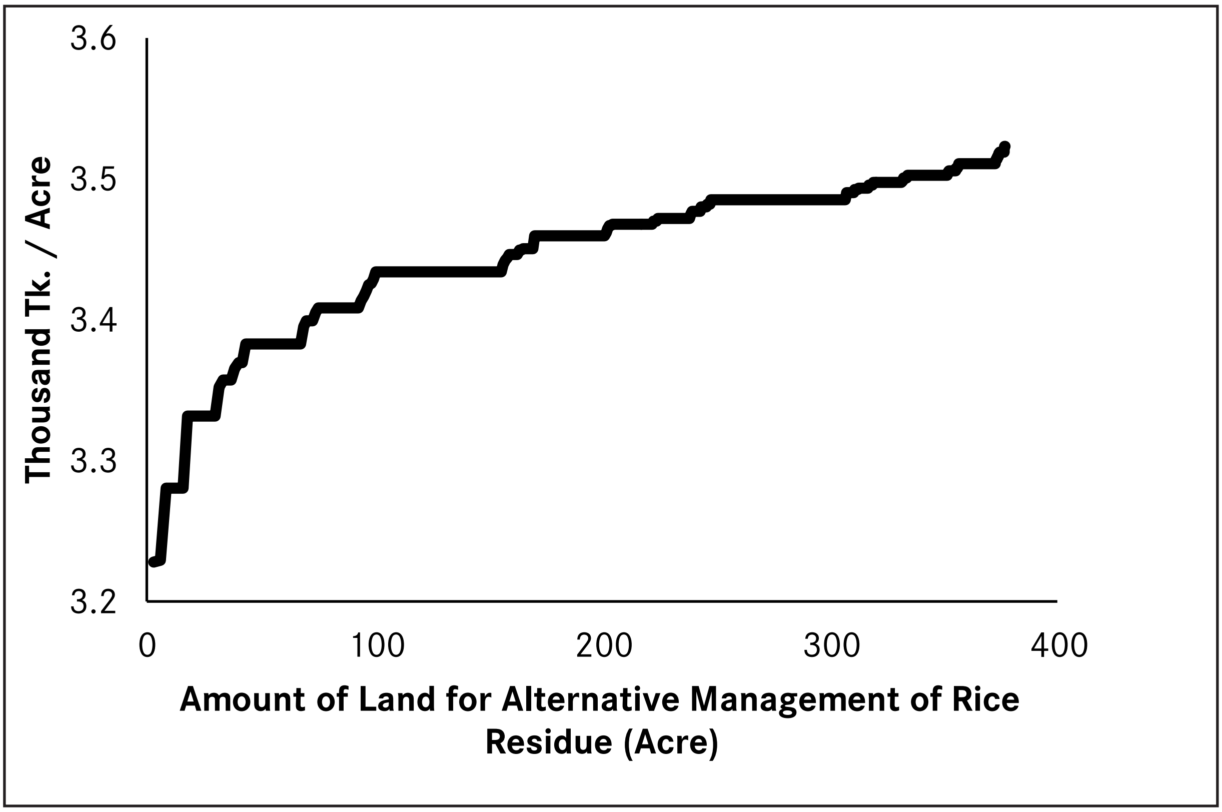
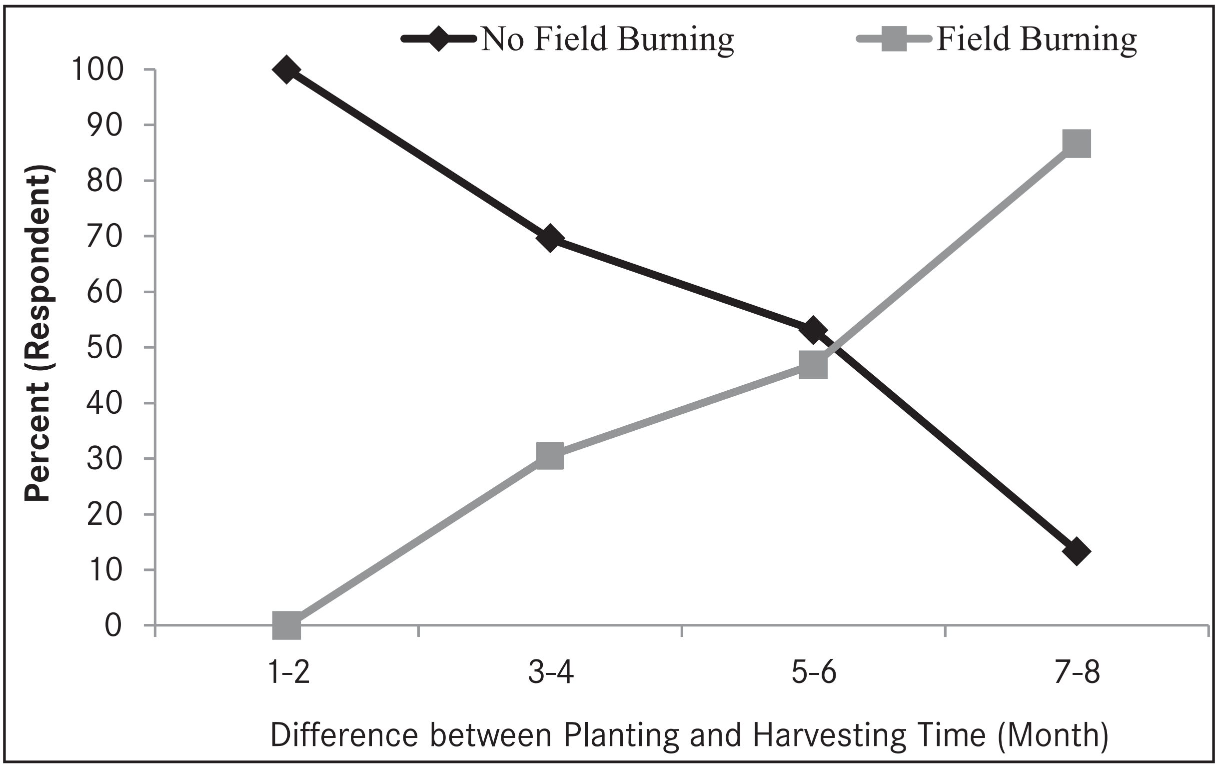
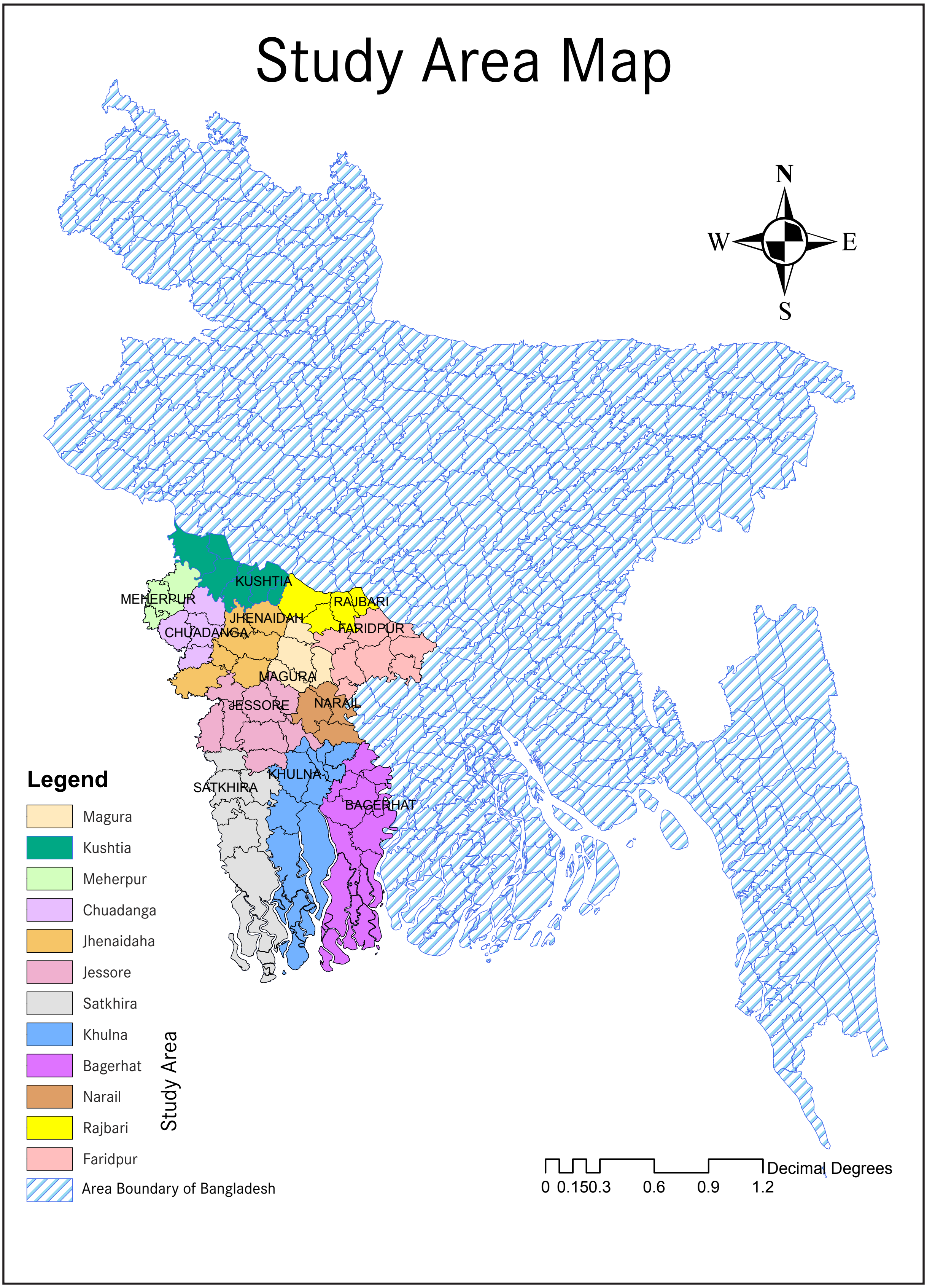


Figure 2: Field Burning of Residue vs. Difference between Planting and Harvesting Time



Map 1: The Study Area



Source: Author’s Compilation Based on ASB (2008)

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