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BURNING CROP RESIDUE:
Farmers' Choice Among Various Practices

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Abstract

Crop residue management practices adopted by farmers have a significant effect on pollution created by the agricultural sector. Broadly, farmers are following the practice of removal, burning and incorporation for the management of crop residue. To find out the determinants of practices adopted by farmers for the management of rice residue; the multinomial model is estimated by using primary data from 400 farmers of Punjab, Pakistan's rice-wheat cropping system. The adoption probability of burning, partial removal and partial burning and incorporation of rice residue management practices increase with farm size, the actual total cost associated with the preparation of field for wheat crop after rice, farming experience and turnaround time between rice harvesting and wheat sowing relative to removal practice. The use of rice residue as fuel and feed decreases the adoption probability of burning practice compared to that of removal practice. To overcome the problems associated with the burning of rice residue, the government should formulate policies for the development/introduction/popularization of technologies about power generation from the residue, enrichment of residue for livestock feeding and incorporation of residue into the soil. Further, regulations about crop residue burning should be implemented and agricultural institutes should also focus on the development of dwarf rice varieties and crop diversification.

Keywords: Rice, Residue Management, Multinomial Logit, Burning, Removal, Incorporation.
JEL Classification: Q12, Q15, Q52.

I. Introduction

The addition of organic content into the soil is essential to maintain and increase its quantity for the maintenance and improvement of soil health [FAO (2011)]. The crop residue is the largest source of organic matter for agricultural soils [Tisdale, et al.

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(1985)]. Different countries produced a large quantity of residues; for example, China produces 626.41 MMT [Yan, et al. (2006)] and India 436 MMT [Murali, et al. (2010)] of agricultural residue. Retaining crop residue on the soil surface or its incorporation in soil has many benefits on soil quality [Blanco-Canqui and Lal (2009), Wilhelm, et al. (2007)]. It helps in maintaining and improving the biological, chemical and physical properties of agricultural soils [Wilhelm, et al. (2007)]. However, many farmers in developing countries either remove residue completely (use it as bio fuels or feed for livestock) or burn crop wastes in the field for better and convenient tillage and planting. Among various options, burning of crop residue in fields is a popular practice in many countries, especially among farmers in developing countries, having simple production technologies [Gadde, et al. (2009) and Shrestha, et al. (2013)] and is a significant source of pollution [UNEP (2010)]. It is estimated that in Asia on average, 730 Tg of biomass is burnt annually and out of which 250 Tg come from the burning in agriculture. Open burning of biomass is emitting 1100 Tg of CO_2, 67 Tg of CO, 3.1 Tg of CH_4, 2.8 Tg of NOx and 0.37 Tg of SO_2 while crop residues burning is contributing 379 Tg of CO_2, 23 Tg of CO, 0.68 Tg of CH_4, 0.96 Tg of NOx and 0.10 Tg of SO_2 [Streets, et al. (2003)]. Open burning of biomass is also one of the major sources of total global emissions of black carbon of 7500 Gg Yr^{-1} [Bond, et al. (2013)] which plays a significant role in the disturbance of the climate system of the earth. The Asian region contributes about 30 to 50 per cent towards total emissions of black carbon [UNEP and C^4 (2002)]. Hence, crop residue burning in the open field is the most undesirable management practice of crop residue from an environmentalist perspective and it results in several direct and indirect adverse effects. Straw burning contributes significantly to smog and haze formation during the harvesting seasons [Zhang, et al. (2016)]. It reduces photosynthesis due to reduction in total solar radiation which in turn leads to decline in productivity [UNEP and C^4 (2002)]. Similarly, Ramanathan, et al. (2008) also reported negative effects of atmospheric brown clouds on crop yields.

Pollutants produced from crop residue burning have adverse effects on the people's health [Nori (2005)] and environment [Badarinath, et al. (2006), Lal (2008)]. The pollutants have a negative impact on the health of human beings, livestock and crops already planted in the area. Massive quantities of CO_2, CO, methane, etc., are generated which are creating greenhouse effects and thus, contributing to climate change [Brady and Weil (2007), EIA (2008)]. Furthermore, biomass combustion processes have partly contributed to unhealthy brown clouds seen over South Asia during winter [Gustafsson, et al. (2009)].

Crop residue is mostly treated as waste by farmers in developing countries. Though crops are grown to feed animals, usually do not produce any residue, but crops cultivated to feed humans', produce a significant proportion of crop wastes in the form of residues. For wheat and high yielding rice, the quantity of residue is almost equal to grain [Smil (1987) (1999)]. Farmers always try to get rid of crop wastes as early as possible after harvesting. Although agricultural waste is valuable if managed in an appropriate way, the hurried response of farmers' results in the use of undesirable methods for waste management. Most farmers carry out the practice of burning to get rid of crop waste, but studies indicate that crop residue is full of nutrients and farmers can make it available for subsequent crops through incorporation. By employing methods other than the burning of residue, farmers can promote sustainable agriculture and decrease the loss of plant nutrients present in the residue [Morello, et al. (2018)].

Rice is an important food grain for the world's population and produced in different cropping systems. In the Indo-Gangetic Plain (IGP), the rice-wheat system is a dominant and important cropping system. It comprises parts of Bangladesh, India, Nepal and Pakistan. A large quantity of rice straw is produced in IGP and usually, rice crop residue is not used as animal feed [Badarinath, et al. (2006)]. Therefore, residues generated from rice crop generally burnt in fields due to the short time span between rice harvesting and subsequent wheat crop sowing. Besides, an excessive amount of residue is problematic and plugs; in conventional and seeding equipment. Therefore, farmers burn off the rice residue. It helps them to perform land preparation operations smoothly by using disc harrow and cultivator with the tractor.

Several field experiments have been done under various management practices of crop residue [Badarinath, et al. (2006), Gadde, et al. (2009), Gupta, et al. (2004), Street, et al. (2003)]. The studies by Ahmed and Ahmad (2014) and Haider (2013) used a dichotomous dependent variable to analyze the burning decision of rice crop residue in the field. They used a binary logit model to find out the determinants of rice residue burning. In Pakistan, actual farm level observations show that farmers use various practices for the residue management i.e., complete removal (REM), complete burning (CBR), removal of upper part of rice plant ('pural' - which are harvested by combine harvester and left in the field) and burning of its lower parts (RPBL) above the soil surface, removal of upper part of rice plant and incorporation of its lower parts (RPIN) into the soil, and complete incorporation (IN). As farmers are adopting various rice residue management practices involving more than two options; therefore, binary logit model used by Ahmed and Ahmad (2014) and Haider (2013) is not appropriate. The present study addresses this issue and makes a significant contribution in literature by identifying the factors that determine the choice of farmers among crop residue management practices in Pakistan.

The remaining part of this paper is as under: the Section II enunciates the review of literature and Section III describes the data and methodology, whereas the Section IV explains the results. Section V concludes the results and suggests some policy implications.

II. Review of Literature

A number of experiments have been conducted to determine the effect associated with various crop residue management practices. Sidhu and Beri (1989) found that chopped wheat residue incorporation into soil improved its chemical and physical properties, stover and grain yields of corn significantly over the non-incorporation of residue. Similarly, Surekha, et al. (2003) and Ganwar, et al. (2006) showed that the application of crop residue increases grain yield over a longer period by improving soil properties and providing more plant nutrients. Malhi and Kutcher (2007) indicated that the continuous burning of crop residue in fields over a long period of time could cause a reduction in carbon; thus, it has an adverse effect on the biological, chemical and physical soil properties. According to Heard, et al. (2006), residue burning resulted in the loss of Sulphur by 75 per cent, K by 35 per cent, P by 24 per cent, N by 98 to 100 per cent and C by over 90 per cent, but when residues of crops left in the field, the most of nutrients it residues are added into soil. IRRI-CIMMYT alliance (2007) reported that cereal crop residues retained about 75 per cent of K, 50 per cent of Sulphur and about 25 per cent of N and P uptake. About 45 to 80 per cent of N is lost due to the burning of crop residues in open fields. Garg (2008) concluded that in-situ incorporation is the best practice, followed by burning and removal. According to Erenstein (2002), burning is a quick way to control diseases, weeds and pests. Hartley and Kessel (2005) reported that the incorporation of rice straw is a mean to keep the nutrients in organic forms. Initially, they are less available than those that are available from the ash of crop residue burnt in the field. However, incorporation of rice straw results in increase of the potential of nutrients recycling, microbial biomass and a higher quantity of organic matter in soil in the long-run. Prasad, et al. (1999) reported that available ‘P’ contents in soil, organic carbon and wheat yield were significantly higher in the rice residue incorporated soil after two years as compared to rice residue burning or removal treatment. Bahrani, et al. (2007) found that the corn yield was maximum when 25 to 50 per cent of residue from wheat crop was incorporated into soil compared to conventional tillage and residual removal followed by conventional tillage. Their study suggests that burning or complete removal of residue should be avoided.

Besides the experimental work, few studies have been conducted using farm level data. For example, Gupta, et al. (2004) reported that burning of wheat straw in the open field has gone up due to an increase in the usage of combine harvester technology. This technology leaves large quantities of rice and wheat straws in the field. The crop residue burning adversely affects soil properties and results in considerable nutrient loss which is important for the agricultural ecosystem stability. Gupta (2012) used a recursive bivariate probit model to find out the influence of various factors on the harvesting mode and disposal method of rice residue. On the basis of data collected from 736 plots in Indian Punjab, he concluded that the use of a combine harvester and farm location have a substantial effect on the burning of rice residue in the field by a farmer. According to him, the age of farmer, farm size and human capital have no influence on the burning of rice crop residue. Haider (2013) identified the factors that influence burning of rice crop residue in Bangladesh’s southwest region. He collected data from 300 farming households. Results of the simple logit model indicate that the distance of the plot from homestead, low elevation land and straw length has a significant positive influence on the practice of rice crop residue burning, while the residue price has a significant negative influence on this decision of the farmers. Pant (2013) estimated the required monetary incentives for the reduction of burning of rice residue in the open fields of Nepal plains. On the basis of data collected from 317 farmers from two districts, he concluded that 86 per cent of the farmers agreed to stop burning rice residue if they were paid US$ 78/ha.

Existing literature indicates that the work done so far has been mostly conducted by the physical scientists to study the effect of various crop residue management practices on the soil and subsequent crops under short and long-run. Since the experimental conditions under field are quite different than the farmer's field conditions, so this requires an analysis of various crop residue management practices at the farm level. In the recent era, satellite information plays an important role in detecting and analyzing crop residue burning in the field. Since crop residue burning is a short lived and sporadic in nature; therefore, satellite monitoring has its limitations as satellites pass through specific locations at a certain time in a day. Hence, all fires cannot be detected by satellites. Furthermore, fire counts do not provide information on crop type unless the information is available on land use and cropping patterns. Moreover, satellite information's have inherent problems relating to meteorology and surface factors that must be considered [Shrestha, et al. (2013)]. This necessitates that field studies may be conducted to supplement the satellite information. Fieldwork is done in India [Gupta (2012), Nepal [Pant (2015)] and Bangladesh [Haider (2013)] is not relevant to Punjab, Pakistan, because of differences in climate, cropping pattern and other factors. Furthermore, work done in other countries and Pakistan [Ahmed and Ahmad (2014)] used simple logit model involving two options, i.e., burning vs. non-burning. Farmers make a particular choice among many options while deciding about the management of rice residue. Thus, it is important to find out the extent of residue burning and the determinants that influence the farmers' choice of rice crop residue management. Hence, this study is conducted to determine the (a) adoption extent of various rice crop residue management practices (b) level of production and field burning of rice residue straw and (c) factors affecting the adoption of various rice crop residue management practices.

III. Methodology

1. Multinomial Logit Model

Logit and probit are the most commonly used models in agricultural technology adoption research. These models are used when the number of choices is two (i.e., whether to adopt or not). When the number of available choices exceeds two, then the extensions of these models, more commonly referred as multivariate models are used. The most commonly used multivariate models are Multinomial Probit (MNP) and Multinomial Logit (MNL). These models have two major advantages over the binary logit and probit models. Firstly, they help to evaluate alternative combinations of management practices or specific practices. Secondly, they account for self-selection and interactions between alternatives [Wu and Babcock (1998)]. A comparison between

MNP and MNL models shows that the statistical properties of both models are asymptotic and on a priori reason, it is difficult to establish the superiority of one method over the other. The MNP model is criticized because even formally identified specifications are often poorly identified in applications which lead to misleading inferences. MNP sometimes fails to convert at a global optimum or yields parameter estimates that are imprecise. The MNL optimizes at its global optimum and not subject to optimization errors except in case of profound misspecification. However, MNL imposes the assumption that the relative odds between any two alternatives are independent of the other alternatives [Dow and Endersby (2004)]. For most of the applications, the independent assumption is neither relevant nor particularly restrictive. Furthermore, MNL specification is tractable and easy to estimate, therefore, this model is preferred over MNP [Dow and Endersby (2004)] and is used in this study. As various options are open to the farmer for rice crop residue management; therefore, residue management decisions can be modeled by using MNL in which farmers make a choice among various practices. MNL analysis of technology adoption has been employed by Bekele and Drake (2003), and Deressa, et al. (2009).

In this study, it is assumed that farmers maximize their utility by adopting crop residue management practices and the utility from each alternative is a linear function of a vector of explanatory variables plus an error term that captures un-modeled effects. Farmers are assumed to select that crop residue management practice Y_i that has the highest utility.

Many farmers are exercising more options on their farms for rice residue management. Under such circumstances, more dominantly followed practice is expected to yield more utility than the other alternatives. As complete incorporation is followed by negligible number of farmers in the study area, so farmers have to make a choice among the other four rice crop residue management options. Consequently, $Prob_{ij}$ (j = 0, 1, 2, 3) denote the probability associated with four choices of rice crop residue management, with j = 0, if dominant practice followed by the farmer is REM j = 1, if dominant practice followed by the farmer is CBR j = 2, if farmer dominantly followed the practice of RPBL and j = 3, if farmer dominantly followed the practice of RPIN. The model for rice crop residue management choice can be given as [Greene (2012)].

$$Prob\,(Y=j) = \frac{e^{\beta_j^{l} x_i}}{\sum_{k=0}^{j} e^{\beta_K^{l} x_i}} \qquad for\, j = 0, 1, 2, 3 \tag{1}$$

This gives the estimation equations for the standard multinomial logit model and β_j is a vector of parameters that relates Table 1 independent variables X_i to the probability that $Y_i = j$.

Because the sum of four probabilities must be equal to one, hence a convenient normalization rule is to set $\beta_o = 0$, the coefficient of the reference group. The probabilities for the four alternatives crop residue management practices then become, as [Greene (2012)].

TABLE 1

Definitions of Variables Used in the Model

Variable	Description
RSMP	0 if the farmer adopted the practice of residue removal (REM), 1 if farmer adopted the practice of complete burning of rice crop residue in field (CBR), 2 if farmer adopted the practice of removal of upper part of rice plant and burning of its lower parts in the field (RPBL) and 3 if farmer adopted the practice of removal of upper part of rice plant and incorporation of its lower parts in soil (RPIN).
GUJRAN	1 if farmer is doing farming in the Gujranwala district and zero otherwise.
AGE	Farmer's age in years.
EXPER	Farmer's experience of farming in years.
PRIMOC	1 if primary occupation of the farmer is farming and zero otherwise.
MATRIC	1 if farmer's educational is upto matric and zero otherwise.
ABMATR	1 if farmer's education is above matric and zero otherwise.
ARIAN	1 if farmer's caste is Arian and zero otherwise.
JAT	1 if farmer's caste is Jat and zero otherwise.
RAJPUT	1 if farmer's caste is Rajput and zero otherwise.
SIZE	Size of operational farm in acres.
OWNEROP	1 if farm is operated by owner and zero otherwise.
OWNCUTEN	1 if farm is operated by owner-cum-tenant and zero otherwise.
NOFRAG	Number of locations where farmer carried out farming.
SILTLOM	1 if silt loam is the dominant type of soil and zero otherwise.
CLAYLOM	1 if clayey is the dominant type of soil and zero otherwise.
ANIMUNIT	Number of animal units owned by the farmer.
TCROVBR	Actual total cost incurred for the preparation of field of wheat crop after rice.
WHEATSN	1 if sowing of wheat is done before the start of December and zero otherwise.
AVAFMMAC	1 if farm machinery for incorporation of rice residue is available and zero otherwise.
FUEL	1 if residue of rice crop is used as fuel for cooking and zero otherwise.
FEED	1 if residue of rice crop is used as animal feed and zero otherwise.
SUPERBAS	Proportion of super basmati rice acreage in to total rice acreage.
INSETDIS	1 if respondent is carrying out burning of rice crop residue in field with an intention to control diseases, weeds, insects and zero otherwise.
TURNAROUND	1 if respondent is carrying out burning of rice crop residue in field with an intention to reduce turnaround time between rice harvesting and sowing of wheat crop and zero otherwise.
CONVFACM	1 if rice crop residue burning in field results in convenience in farm machinery use and zero otherwise.
TRANP	Total cost borne by respondent to carry out rice crop residue collection and transportation from field.

Source: Authors' estimation.

$$Prob\ (Y = j) = \frac{e^{\beta_j^{l} x_i}}{1 + \sum_{k=1}^{j} e^{\beta_K^{l} x_i}} \qquad for\ j = 1, 2, 3 \tag{2}$$

$$Prob\ (Y = 0) = \frac{1}{1 + \sum_{k=1}^{3} e^{\beta_K^{l} x_i}} \tag{3}$$

The natural logarithms of the odd ratio of Equation (2) and (3) gives the following equation.

$$\ln\left(\frac{P_{ij}}{P_{io}}\right) = \beta_j X_i \tag{4}$$

The dependent variable is the log of one alternative residue management practice (CBR, RPBL, RPIN) relative to the base residue management practice (REM). It shows the relative probability of each choice to the reference choice probability. The coefficients estimated for each choice measure the effects of X_i's on the likelihood of the farmer's choice with reference to relative choice. The coefficient for each explanatory variable for the reference choice is simply negative of the sum of coefficients of other choice [Rahji and Fakayode (2009)].

The coefficients of the independent variables obtained by the multinomial logit model have no straight interpretation like that of ordinary least squares regression model. As the estimated coefficients sign and magnitude are relative to the reference group; therefore, it is difficult to carry out the interpretation of estimated coefficients of the model. Hence, the explanatory variables marginal effects on the choice of rice crop residue management practices need to be derived [Sherrick, et al. (2004)]. The marginal effect of the independent variables on the particular choice of rice crop residue by the respondents can be estimated by taking derivatives of the probabilities with reference to explanatory variables [Greene (2012)], i.e.,

$$\frac{\partial P_j}{\partial X} = P_j\ (\beta_j - \sum_{k=0}^{j} P_k \beta_k) \tag{5}$$

The marginal effect $\partial P_j / \partial X$ represents the change in the probability of outcome 'j' resulting from one unit increase in X, for the given set of values of other independent variables. The marginal effects are not constant as they depend on the probabilities, which depend nonlinearly on all independent variables. Furthermore, it may be noted that neither the magnitude nor the sign of marginal effects require any relationship with the specific coefficient. They depend upon the magnitude and sign of many coefficients [Wu and Babcock (1998)]. The multinomial logit model was estimated by using maximum likelihood. Model estimates are consistent and efficient asymptotically provided that MNL model is correctly specified. This method chooses a set of parameters to maximize the likelihood that the actual choice indicated independent variable for respondents would occur for the given values of explanatory variables [Pindyck and Rubinfeld (1998)]. The definitions of the variables considered in the model are described in Table 1. A brief justification of independent variables considered in the empirical model is as under:

Geographic location of the farm in Gujranwala (GUJRAN): Since socio-economic and climatic factors may vary among locations, geographic location is considered as an important variable influencing rice residue management [Gupta (2012), Ahmed, et al. (2015)]. Although it is difficult to say anything specific about the impacts of the geographic location of farm, we expect a difference between Gujranwala and Sialkot districts. However, the expected sign for this variable is not known a priori.

Age (AGE): Age is used as a proxy for maturity of the respondent, and results in careful handling of rice residue [Gupta (2012), Haider (2012) Ahmed, et al. (2015)]. Therefore, older farmers are expected to follow more incorporation practices than younger farmers.

Farming experience (EXPER): Experience is used as a proxy for the potential of farmers to handle rice residue carefully. The experienced farmers recognize the importance of rice residue in maintaining the soil fertility status of their farmlands and therefore, we expect experienced farmers to be less inclined towards the burning practice than less-experienced farmers. Many technology adoption studies treat experience as a determinant [Gould, et al. (1989)].

Primary occupation (PRIMOC): If farming is the primary occupation of the farmer, he might be more interested in the sustainable use of the land resource to ensure his livelihood in the long run [Ahmed, et al. (2015)]. This is expected to have a negative effect on the burning decision.

Education (MATRIC, ABMATR): Since a higher level of education implies better technical knowledge [Gould, et al. (1989), Harper, et al. (1990), Sherrick, et al. (2004), Wu and Babcock (1998)], know-how on residue management and farming skills, we expect educated farmers to have a better understanding of the negative effects of burning rice residue on soil properties and nutrients. This might incline them to practice non-burning alternatives in place of the open field-burning of residue.

Caste (ARIAN, JAT, RAJPUT): Caste is an important social institution that influences the adoption of technologies [Floyd, et al. (1999), Ahmed, et al. (2015), Aryal, et al. (2018) and Krishna, et al. (2019)]. It is difficult to say anything about the direction of the impact of different castes (JAT, ARIAN, RAJPUT and others) on the extent of the adoption of various residue management practices. However, caste is an important social variable.

Size (SIZE): Scale of farming is identified by the literature as an important determinant of technology adoption [Nowak (1987), Cary (1992), Cary and Wilkinson (1997), Neill and Lee (2001) and Ahmed, et al. (2015)]. Since the availability of labor and the num-

ber of animal units per unit area decline with increase in farm size, we expect large farmers to resort to crop residue burning practice more than owners of small farms.
Owner operator (OWNEROP): Since owner operators would be more concerned with the sustainability of the land resource than tenants and owner-cum- tenants, we expect them to adopt other alternatives to open field burning [Gupta (2012) and Ahmed, et al. (2015)].
Number of fragments (NOFRAG): As an increase in the number of fragments of a farm has a negative impact on the efficiency of resource use, which would result in less production of paddy and residue, thus a relatively larger proportion of the residue would be used as feed for animals and domestic cooking purposes [Gupta (2012) and Ahmed, et al. (2015)]. Therefore, we expect the number of fragments to have a negative effect on the probability of burning rice residue.
Soil type: Silt loam (SILTLOM) and clay loam (CLAYLOM) soils are more suitable for the cultivation of rice than sandy soil, which would, in turn, lead to a relatively higher quantity of rice residue than other soils. Since farmers might be incorporating residue into the silt loam and clay loam soil in order to improve the physical properties of that soil, so we expect less chance of burning rice residue on these soils, which is bound to have a negative effect on the burning decision [Gupta (2012) and Ahmed, et al. (2015)].
Number of animals (ANIMUNIT): Farm animals produce manure besides milk, meat, etc., Manure is added to soil to improve the organic matter and nutrient status. An increase in the number of animals on the farm is expected to meet the requirement of organic matter. This is likely to encourage farmer to practice burning instead of incorporation, so we expect this variable to have a negative effect on incorporation.
The actual total cost incurred for the preparation of wheat field (TCROVBR): Various operations are performed by using tractor and equipment for preparation of wheat crop field after harvesting of rice crop. Incorporation of rice residue increases the cost of preparation of wheat field compared to the removal/burning practice; therefore, it is expected to have a negative influence on incorporation and positive effect on removal/burning decision [Haider (2012) and Ahmed, et al. (2015)].
Sowing of wheat on time (WHEATS): Timely sowing of the wheat crop before the start of December after the rice crop ensures a higher yield. Farmers must do all that can reduce the turn-around time between rice harvesting and wheat sowing. Thus, we expect the residue incorporation practice to be lower for timely planters of wheat over the late planters.
Availability of farm machinery for incorporation (AVAFMMAC): Farm machinery availability facilitates the incorporation of rice crop residue. Therefore, we expect a positive influence of this variable on the incorporation decision.
Use of residue: Use of rice residue as fuel (FUEL) and feed (FEED) for cooking is likely to discourage the incorporation and burning off residue [Haider (2012)]. Therefore, it is expected that both variables have a negative affect on the incorporation and burning decisions.

Super Basmati rice acreage (SUPERBAS): The fine grain super basmati rice variety matures late and yields more residue than the coarse varieties, which mature early and yield less residue. Therefore, to expedite the timely sowing of wheat and for easy management of residue, we expect residue incorporation practice to be lower in the case of super basmati rice than other coarse grain varieties [Ahmed, et al. (2015)].

Intention to control diseases, weeds and insects (INSETDIS): If farmer is carrying out the practice of rice residue burning with an intention to control diseases, weeds and insects, then we expect a negative influence on incorporation decision.

Reduction in turn-around time (TURNAROUND): Since the timely sowing of the wheat crop after the rice crop ensures a high yield, farmers must do all they can to reduce the turn-around time between the harvesting of rice and the sowing of wheat [Ahmed, et al. (2015)]. Thus, we expect the timely planters of wheat to adopt the practice of rice crop residue burning more over the late planters.

Convenience in use of farm machinery (CONVFACM): Use of farm machinery conveniently refers to the ease with which the farmer can prepare the land for the next wheat crop by using machinery [Ahmed, et al. (2015)]. Therefore, we expect an increase in convenience to encourage the burning of residue over incorporation.

Total cost borne by respondent to carry out collection and transportation of rice residue from field (TRANP): An increase in cost of rice crop residue collection and transportation is likely to encourage farmers to adopt the burning and incorporation practices and we expect its positive effect on burning and incorporation decisions [Haider (2012)].

2. Study Area and Data

The study is undertaken in the rice-wheat cropping system in the province of Punjab, Pakistan. Sialkot and Gujranwala are the most important districts in this province in terms of production and acreage of rice in this cropping system [Government of Punjab (2009)]. Therefore, these districts are selected for the study. The study follows two stage sampling procedure. In the first step, 10 villages are randomly selected from the 36 villages already selected randomly from each district by the Federal Bureau of Statistics (FBS) for the estimation of various crop production and acreage by using the sampling frame developed for the country. For each village, farmers list was prepared and randomly, 20 farmers were selected for data collection. A comprehensive questionnaire was developed and modified after pre-testing in the rice-wheat cropping system for the collection of data from 400 respondents. The data pertained to the extent of adoption of various residual management practices, demographic characteristics of farmers, farm size, tenure type, farm machinery availability for the incorporation of rice residue, soil type, variety sown, etc. The data were collected by carrying out personal interviews of farmers in the rice-what cropping system.

IV. Results

In the study area, 92 per cent respondent's primary occupation was farming. Rice and wheat were the dominant crops in the rice-wheat cropping system and shared more than 40 per cent each of the total cropped area. Super basmati shared 70.63 of the total rice area followed by Basmati 386 (21.37 per cent) and other varieties (8 per cent). Cost of rice crop residue management and wheat field preparation was the highest for REM (i.e., US$ 55) and the lowest for CBR (i.e., US$ 41), indicating that rice crop residue burning infield is the most economical method. Similar results have been mentioned by [Zhang, et al. (2016)]. About 87 per cent and 8 per cent of the removed crop residue was used as fuel and feed, respectively, while only 5 per cent was sold, 63 per cent respondents reported the use of residue as feed. Inconvenience in farm machinery usage in the presence for crop residue and short turnaround time between rice crop harvesting and wheat crop sowing were the major reasons for the rice crop residue burning in open fields and is reported by 65 per cent and 46 per cent of the farmers, respectively. Use of rice crop residue as feed for animals and as fuel for home cooking ae the major reasons for not burning of crop residue in fields were reported by 95 per cent and 24 per cent respondents, respectively. Major reason for increasing trend in burning was the use of combine harvester. About 27 and 15 per cent of the farmers thought that rice crop residue burning in the field decreases and increases soil nutrients, respectively, while 12 per cent reported no effect and 46 per cent did not know the effect of rice crop residue burning in field on soil nutrients. More or less similar effects were reported of residue burning on the soil organic matter. Rice crop residue burning had adverse impact on the environment was reported by 48 per cent respondents.

1. Adoption of Residue Management Practices

In the study area, management of rice crop residue by respondents shows that REM is the dominant practice adopted by 48 per cent farmers. After it, farmers' follow CBR (35 per cent) and RPBL practice (12 per cent). RPIN and complete incorporation practice is adopted by negligible percentage of farmers. In Bangladesh, 41 per cent of the farmers practised complete and partial burning of rice residue compared to 47 per cent in Pakistan (Table 2). This difference may be due to high residue price (i.e., USD 221.72 per hectare) in Bangladesh compared to almost zero prices in Pakistan. High prices encouraged farmers to practice complete and partial removal of rice residue in Bangladesh. In terms of overall rice area, CBR is practised on maximum acreage (58.27 per cent) followed by REM (24.84 per cent), RPBL (11.92 per cent) and RPIN (4.13 per cent). More or less similar pattern is observed under various varieties of rice (Table 3).

TABLE 2

Rice Residue Management Practices Followed by the Farmers in Pakistan and Bangladesh

Rice Residue Management Practices	Pakistan[a]	Bangladesh[b]
100 per cent removal	48	54
100 per cent burning	35	3
Removal of upper part and burning of lower part	12	38
Removal of upper part and incorporation of lower part	4	4
100 per cent incorporation	0.8	0.5

Source: a) Based on the field survey data collected for the present study; b) [Haider (2013)].

It is noted that the total cost incurred in rice crop residue management and preparation of the field for wheat crop after the rice is the lowest for CBR and is followed by REM practice. It was also observed that total rice area under open field burning of its residue in this study is 70 per cent (i.e., the area where CBR and RPBL practices are carried out). It is higher than the adjacent Indian Punjab open field burning area of 55 per cent as reported by [Badarinath, et al. (2006)]. The difference in open field burning of Pakistani Punjab and Indian Punjab may be because of several reasons, but in particular, in Indian Punjab, farmers grow coarse varieties of rice which mature early and generate relatively less rice straw. Further, there is sufficient turnaround time between rice harvesting and wheat crop sowing, and farmers can prepare the field for the subsequent wheat crop by using farm machinery. On the other hand, in the present study area, farmers grow fine rice varieties especially super basmati, which matures late and produces relatively more rice straw. Moreover, there is a short time between rice harvesting and wheat crop sowing.

TABLE 3

Proportion of Rice Area under Various Residue Management Practices across Varieties

Variety	Area (acres)	Pattern of residue management (per cent of total rice area)				
		REM	RPBL	CBR	RPIN	IN
Super basmati	2676.89	24.64	12.04	59.40	2.72	1.20
Basmati 386	809.94	26.30	11.42	53.10	9.18	0.00
Other varieties	302.99	22.60	12.21	62.05	3.14	0.00
All varieties	3789.82	24.84	11.92	58.27	4.13	0.84

Source: Based on the field survey data collected for the present study.

2. Production and Field Burning of Rice Straw

The results show that the production of rice residue per acre is 1602kg. However, it varied from 1465kg to 1722kg per acre for various varieties of rice (Table 4). Burning of residue is 932kg per acre under the practice of RPBL, while the quantity burnt is 1038kg under the practice of CBR. The study reveals that around 45 per cent of rice crop straw produced is burnt in the field. This percentage is higher than the South Asian countries (25 per cent) and India (14 per cent). However, burning of rice straw in open field is substantially higher in the Philippines and Thailand, where 95 per cent and 48 per cent of produced residue is burnt in fields, respectively [Gadde, et al. (2009)]. The difference in the extent of burning of rice residue in open fields between Pakistan and India is due to the fact that we are comparing the figures of entire India with the rice wheat cropping system of Punjab, Pakistan. In fact, open field burning in India is the main activity in the states of Haryana, Punjab, and Utter Pradesh [Gadde, et al. (2009)]. Badarinath, et al. (2006) reported that about three-fourth of crop residue is burnt in Indian Punjab.

TABLE 4

Production and Field Burning of Rice Residue by Variety

Variety	Production of residue per acre (in kg)	Field burning of rice residue per acre (in kg)	
		RPBL	CBR
Super basmati	1581	927	1004
Basmati 386	1722	1000	1192
Other variety	1465	788	932
Overall	1602	932	1038

Source: Based on the field survey data collected for the present study.

3. Factors Affecting the Adoption of Rice Crop Residue Management Practices

For the estimation of parameters, statistical software STATA was used. Parameter estimates for the multinomial logit model of rice residue management decisions are reported in Table 5.

All the coefficients in the estimated model are simultaneously equal to zero under the null hypothesis is rejected on the basis of the likelihood ratio test. This shows that the model has strong explanatory power. The Pseudo R^2 also gives an indication of a decent model (Hensher, Rose and Green, 2015) and the value is similar to other studies [Hendricks, (2007)].

TABLE 5

Multinomial Logit Results with Removal of Rice Crop Residue as the Base Category

Variable	Complete burning of rice residue in field		Removal of upper part of rice plant and burning of its lower parts		Removal of upper part of rice plant and incorporation of its lower parts	
	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
GUJRAN	0.7182[a]	0.3944	1.1562**	0.4538	2.3848**	0.8819
AGE	-0.0415[b]	0.0218	-0.0172	0.0257	-0.0834	0.0555
EXPER	0.0658*	0.0218	0.0411[b]	0.0258	0.1244*	0.0568
PRIMOC	-0.5986	0.7275	-0.0089	0.9583	17.0050	6542.91
MATRIC	0.1952	0.4050	-0.1622	0.4700	-1.1275[b]	0.8464
ABMATR	-0.5195	0.8119	-0.9168	1.0626	-34.9151	171E+07
JAT	-0.1022	0.4569	0.0113	0.5313	1.5243	1.4508
ARIAN	-0.2410	0.8179	0.2951	0.9419	3.0283[a]	1.7515
RAJPUT	1.7645*	0.7328	1.3350[b]	0.8419	3.8261*	1.6266
SIZE	0.1028**	0.0223	0.0957**	0.0250	0.0513[b]	0.0397
OWNEROP	-1.4324	1.4978	-2.9407*	1.2752	14.6375	6542.91
OWNCUTEN	-1.0969	1.5389	-3.1447*	1.3830	15.6904	6542.91
NOFRAG	0.2108	0.2667	-0.5578[b]	0.3484	0.6723	0.5053
SILTLOM	0.0560	1.2959	0.0305	1.5008	-2.4249[b]	1.3618
CLAYLOM	-0.3614	1.2991	0.3477	1.4928	-27063[a]	1.3660
ANIMUNIT	-0.0399	0.0193	-0.0563*	0.0291	-0.0843*	0.0621
TCROVBR	0.0004*	0.0002	0.0005**	0.0002	0.0007[b]	0.0003
WHEATSN	0.6398*	0.5485	-0.1611	0.6174	-0.5406**	0.9663
AVAFMMAC	-0.7045	0.6818	-2.0553[a]	1.1400	-0.7700	1.1861
FEED	-3.9282**	0.5557	0.2968	0.7757	1.1490	1.4380
FUEL	-1.3104*	0.6216	-0.1080	0.6532	2.1772**	0.8852
SUPERBAS	0.0058	0.0055	-0.0026	0.0055	-0.0199*	0.0086
INSETDIS	0.1455	0.5719	0.0905	0.6535	1.3492	0.9784
TURNAROUND	1.2372[a]	0.6849	0.9672[b]	0.7362	-0.2696	1.4971
CONVFACM	2.1161**	0.5452	1.6415**	0.6017	0.5442	0.9510
TRANP	-0.0001	0.0004	0.0001	0.0004	-0.0005	0.0013
CONSTANT	-0.2101	2.4108	-1.3500	2.6264	-38.1393	-

*, **, a and b indicates significant differences at 1, 5, 10 and 20% levels of probability, respectively.
Number of observations = 396. LR x^2 0.01(78) = 405.9; Prob x^2 > = 0; Log likelihood = -237.13204; Pseudo R^2 = 0.4612.

Significance of regression coefficients shows the extent with which a variable contributes to the probability of selecting a particular rice crop residue management practice relative to its influence on the reference practice, i.e., removal of residue (REM). The positive sign for an explanatory variable shows that when its value increases, it increases the probability of choosing a particular rice residue management practice with respect to the reference practice. The negative sign for an explanatory variable indicates that when its value increases, it decreases the probability of selecting a residue management practice relevant to the reference practice. Let us consider first the effect of the geographic location of a farmer. The preponderance of positive coefficients for Gujranwala (GURJAN) for various residue management practices indicates that the location of farmer in this district is more likely to adopt CBR versus REM, RPBL versus REM, and RPIN versus REM of rice crop residue. The effect of length of farming experience indicates that more experience makes it more likely to adopt CBR versus REM, RPBL versus REM, and RPIN versus REM. This might be due to the fact that with the introduction and more use of combine harvesters, it is easy and convenient for the farmer to manage the rice residue by using practices other than the removal of residue. Similarly, one can interpret the coefficients of other explanatory variables for various practices of residue management with reference to the removal practice of residue.

The explanatory variable's marginal effect on the choice of particular practice of rice residue management practice at overall sample means values are reported in Table 6. The study results indicate that the presence of the farm in the district of Gujranwala increased the adoption probability of CBR, RPBL and RPIN by 0.1126, 0.0906 and 0.0001, respectively compared to that of REM. This might be due to large farm size, and consequently a smaller number of animals per acre in the district of Gujranwala as compared to the district of Sialkot, where residue of rice crop is more frequently used as animal feed. More farming experience of farmers results in adoption of CBR, RPBL and RPIN while less frequent REM. This might reflect their long farming experiences in cultural practices. The results show that the adoption probability of CBR practice increases with farming experience of farmer, farm size, sowing of wheat before the end of November, actual total cost associated with wheat field preparation after rice, convenience in the use of farm machinery, reduction in turnaround time between harvesting of rice and sowing of wheat crop, and Rajput caste compared to REM practice. An increase in farm size results in a smaller number of animals per acre and associates with less demand of rice crop residue as animal feed and consequently more burning. Turnaround time reduction between rice harvesting and wheat sowing is very important for achieving higher yield of wheat. This requires immediate clearing of field from rice crop residue for usage of farm machinery conveniently. The same is achieved through burning of residue.

Furthermore, the adoption probability of CBR decreases with the age of respondents, usage of rice residue as animal feed and usage of residue as cooking fuel by the farmers relative to REM practice. This finding may indicate that old farmers adopted this practice less frequently. Furthermore, usage of rice residue by farmers as fuel for domestic cooking and as feed for animals resulted in the practice of burning less frequently and thus considered the importance of other practices in the management of rice residue.

As with CBR, the adoption probability of RPBL practice increases with farm size, turnaround time between rice harvesting and wheat sowing, the total cost associated

TABLE 6

Estimated Marginal Effects of Variables for Various Crop Residue Management Practices

Variable	REM	CBR	RPBL	RPIN
GUJRNAN	-0.2033	0.1126	0.0906	0.0001
AGE	0.0089	-0.0090	0.0001	-3.72E-06
EXPER	-0.0149	0.0136	0.0013	5.35E-06
PRIMOC	0.1178	-0.1465	0.0285	0.0002
MATRIC	-0.0276	0.0540	-0.0263	-0.0001
ABMATR	0.1488	-0.0861	-0.0625	-0.0001
JAT	0.0187	-0.0248	0.0060	0.0001
ARIAN	0.0210	-0.0702	0.0481	0.0010
RAJPUT	-0.3614	0.3287	0.0321	0.0006
SIZE	-0.0252	0.0198	0.0055	2.26E-09
OWNEROP	0.4177	-0.0789	-0.3410	0.0021
OWNCTEN	-0.3831	-0.3891	-0.1900	0.9623
NOFRAG	-0.0062	0.0762	-0.0701	0.0001
SILTLOM	-0.0123	0.0119	0.0007	-0.0002
CLAYLOM	0.0434	-0.1006	0.0573	-0.0001
ANIMUNIT	0.0110	-0.0068	-0.0042	-3.53E-06
TCROVBR	-0.0001	0.0001	0.0000	3.03E-08
WHEATSN	-0.0998	0.1485	-0.0486	-0.0001
AVAFMMAC	0.2220	-0.1054	-0.1165	0.0000
FEED	0.5958	-0.7286	0.1328	0.0001
FUEL	0.2169	-0.2546	0.0373	0.0005
SUPERBAS	-0.0009	0.0015	-0.0006	-1.24E-06
INSETDIS	-0.0331	0.0302	0.0028	0.0001
TURNAROUND	-0.2698	0.2382	0.0317	-0.0000
CONVFACM	-0.4602	0.3866	0.0737	0.0000
TRANP	6.96E-06	-0.0000	0.0000	-2.79E-08

Source: Based on the field survey data collected for the present study.

with the field preparation for the wheat crop after rice, and convenience in the use of farm machinery. However, owner operator, owner cum-tenant operator, number of fragments of the operational farm, number of animal units and farm machinery availability for rice residue incorporation had a significant negative effect on the adoption probability of RPBL practice. This demonstrates that these variables decrease adoption of RPBL and hence, favour sustainability of land resources. Owner operators and owner-cum-tenants are more concerned with long term yield than the tenant operated farms. An increase in the number of animals is likely to increase the demand of rice crop residue as feed and consequently favour less removal of 'pural' and burning of the lower part of rice crop residue.

The adoption probability of RPIN practice decreased on farms with silt loam and clay loam soils relative to the REM practice. This demonstrates the importance of soil type in the choice of this practice. Animal strength had negative significant effect on the adoption probability of PRIN practice compared to that of REM practice. This finding may indicate that maintenance of a greater number of animals reduces the need for adoption of RPIN practice. The adoption probability of PRIN declines on farms where farmers are sowing wheat before the end of November, which is the optimum time for its sowing. This finding may indicate that REM of residue helps in sowing of wheat at an appropriate time while RPIN practice delays the result because it requires more time of farmers for the preparation of land with the incorporation of residue. Results further indicate that the adoption probability of RPIN practice increases with an increase in the proportion of rice area occupied by super basmati. This finding may indicate that varieties like super basmati, which mature late discourage the farmers in the adoption of RPIN and encourage REM practice. Furthermore, larger farm size, use of residue as fuel, Rajput caste, Arian caste, higher total cost associated with the residue burning increase the adoption probability of RPIN practice.

V. Conclusion and Policy Implications

This study highlights the determinants of rice crop residue burning in rice-wheat cropping system of the Punjab, Pakistan. Crop residue burning has negative impacts on the environment due to the emission of aerosols and black carbon during burning process and results in global warming. Moreover, this act of farmers has a negative impact on the soil's quality of their land and yield of crops under the longer term. In the study area, farmers are dominantly following the practice of CBR for the management of rice residue. One of the reasons for this choice is the association of the lowest cost with complete burning of rice residue and wheat field preparation after rice crop. Thus, economic considerations (i.e., cost saving) have a significant impact on the tendency to adopt CBR practice. The effect of various factors that influence the adoption probability of various practices of residue management show that the adoption of CBR as well as RPBL is affected positively by farm size, actual total cost associated with wheat field preparation after rice, convenience in the usage of farm machinery, turnaround time reduction between harvesting of rice crop and sowing of wheat crop, farming experience and presence of farm in the district of Gujranwala. However, the adoption probability of CBR decreases with an increase in the age of respondents, the use of rice residue as fuel for cooking and feed for the animal by the farmer. Furthermore, owner operator, owner-cum-tenant, number of farm fragments, animal strength and availability of farm machinery for the rice residue incorporation decrease the probability of adopting RPBL relative to REM. Hence to reduce emissions from crop residue burning, promotion of usage of rice residue as feed for animals, farm machinery availability for the incorporation of residue in fields and implementation of regulations to reduce burning of crop residue could be possible solutions. Further, there is strong need to highlight the benefits associated with the residue incorporation into soil on soil fertility, soil organic matter, soil moisture retention, nutrient cycling, carbon storage, and other environmental and health effects [Turmel, et al. (2015)].

Results show that super basmati variety, which produces relatively more residue, has a significant negative effect on incorporation practice. Therefore, there is a need to develop dwarf varieties of rice to reduce the straw production and consequently its availability for field burning. These varieties can also ensure enough time to the farmers for performing various operations between the one crop harvesting and sowing of the next crop [Haider (2012) and Haider (2013)].

Diversification can be used as a tool to reduce the total quantity of crop residues produced and emission of GHG besides augmenting farm income, alleviating poverty, generating employment, and conserving water and soil resources (Ryan and Spencer, 2001; Pingali and Rosegrant, 1995; Von Braun, 1995). Various techniques can be used for diversification to reduce crop residue burning. This can be achieved through the cultivation of alternative crops like vegetables, pulses, oilseeds and fruits that produce less crop residue.

The results of the study show that the use of rice residue as a fuel reduces the adoption probability of BPLP practice. As there is sufficient evidence that crop residue can be used as fuel in power generation plants [Nguyen, et al. (2013), Hiloidhari and Baruah (2011), Karaj, et al. (2010), Jingura and Matersgaifa (2008), Shyam (2002), Ergudenler and Isigigur (1994), Freedman (1983)]; therefore, crop residues can be converted into energy products by using new emerging technologies [Idania, et al. (2010) and Scarlat, et al. (2010)].

The use of rice residue as feed decreases the probability of adopting BPLP practice. Thus, in order to manage the crop residues efficiently, the government should place emphasis on its use as feed for animals through enrichment of residues. To improve the productive and reproductive efficiency of animals by farmers, various supplements like micronutrients and other feed additives like minerals, vitamins, enzymes, antioxidants, antitoxins, etc. can be added to residue. Governments should take appropriate measures including provision of subsidy to the farmers to introduce and promote processing technologies involving mixing of chopped straw with different ingredients [FAO (2012)]. These measures should be taken on a priority basis as the supplies of various crop residues have increasing trend, especially due to increase in cereal production (NIANP Feed Disc., 2005) and stagnating or shrinking area under green forage crops despite the fact that the number of animals is increasing. Farmers also need to be familiarized with the benefits of enriched straw to be used as fodder for livestock through extension department.

Results of the study indicate that the cost associated with the wheat field preparation for its sowing after harvesting of rice encourages farmers to adopt the practice of burning and consequently negligible proportion of farmers followed the practice of incorporation even though the incorporation of residue has positive effects on the soil's biological, chemical and physical properties [Kumar, et al. (2015)]. It also results in higher crop yield [Bahrani, et al. (2007) Tripathi, et al. (2007), Surekha, et al. (2003), Prasad, et al. (1999)]. Given the benefits associated with incorporation of crop residues, governments should take necessary initiatives for the development, introduction and popularization of residue incorporation technologies, as no appropriate technologies for the incorporation of crop residues are available. Therefore, research institutes and agricultural universities may be provided more funds for the development of machines and equipment like Indian Happy Seeder for crop residue incorporation. Provision of new agricultural equipment at subsidized rates to farmers will help in their introduction and more use. Further, organizing demonstrations and highlighting benefits of incorporation by the Department of Agriculture will encourage farmers to adopt machines and equipment connected with the incorporation of residues.

Results of the present study show that the major proportion of residue produced from rice cropped area is burned, which has adverse effects on environment. Therefore, it is suggested that the Government should formulate policies for regulation of agricultural crop residue burning. This may involve establishment of pollution control board and setting up Ambient Air Quality Standards for the abatement, control and prevention of pollution caused by burning of crop residues. Policy for monitoring crop residue management also needs to be framed including satellite based remote sensing techniques. Satellite based monitoring systems can help to monitor crop residue burning in open fields. Besides this system, the involvement of police stations, revenue department and other agencies will also be useful for monitoring burning activities and to ensure the implementation of complete ban on burning of crop residues. No farmer should be allowed to burn any crop residue unless it is for the purpose of education, research or disease control. Any person who is violating this regulation should be liable to penalties in terms of fines and jail terms up to certain period. Furthermore, there should be a system of rewards in term of payment for non-burning of crop residue [Pant (2013)]. Farmers need to be trained about the direct and indirect costs of burning residue through electronic media and other measures.

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