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Agro-environmental Revolution in Punjab: Case of the Happy Seeder Technology

Ridhima Gupta

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Indian Statistical Institute, Delhi
Planning Unit
7, S. J. S. Sansanwal Marg, New Delhi 110016, India

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Ridhima Gupta†

Abstract

Biomass burning of agricultural field residue (stalks and stubble) during wheat and rice harvesting periods in the Indo-Gangetic plains has led to substantial emission of trace gases and particles. This paper seeks to address the regulation of emissions from open field burning of rice residue in Punjab, India by first uncovering the factors that explain on field residue burning of rice residue in Punjab. The results suggest that the use of a combine harvester was the single most important determinant of the decision to burn rice residue. The decision to use the combine harvester was in turn determined by the rice variety sown by a farmer. Rice residue are largely burnt, as machinery for planting into loose residue was hitherto unavailable. The recently developed Happy Seeder technology overcomes this problem. It is a tractor-mounted machine that can sow wheat into the rice residue left by the combine harvester thereby precluding its burning. I conclude that Happy Seeder is a low-cost alternative to open field burning of rice residue vis-a-vis conventional tillage. I also find no evidence of an increase or decrease in mean yield of wheat from incorporation of the residue with Happy Seeder compared to conventional tillage. These results have important implication for mitigation policies to reduce residue burning in this region.

1 Introduction

Biomass burning of agricultural field residue (stalks and stubble) during wheat and rice harvesting periods in the Indo-Gangetic plains is an important source of atmospheric pollution in this region (Venkataraman et al., 2006). Consequently, regional climate, and in turn crop output (Auffhammer et al., 2006), and the health (Long et al., 1998) of the population are adversely affected. What factors explain the burning of rice residue on field in Punjab, India? What are the alternatives to open field burning of rice residue in Punjab, India? In this paper, I explore these 2 questions, both extremely important given that understanding why farmers burn is imperative to prescribing policy reforms. Hence I hope to make a contribution to mitigation policies to reduce rice residue burning in this region.

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†Research Fellow,Indian Statistical Institute,Delhi. Email:g.ridhima@gmail.com

The ‘rice-wheat cropping system’ (RWCS) is the dominant cropping system in South Asia (Hobbs and Morris, 1996). This system involves the growing of rice and wheat in rotation throughout the year. Rice and wheat may be grown in the same plot in the same year or in different plots in the same year or in the same plot in different years. Uttar Pradesh, Punjab, Haryana, Bihar, Madhya Pradesh, and Himachal Pradesh have the largest areas under rice-wheat cropping systems among Indian states.

Koopmans and Koppejan (1997) estimated that about 507,837 thousand tonnes of on field crop residue was generated in India during 1997 of which 43% was rice and 23% wheat. The estimates from Streets et al. (2003) imply that 16% of this crop residue was burnt. The results from Venkataraman et al. (2006) suggest that 116 million metric tonnes of crop residue was burnt in India in 2001 with a strong regional variation. Open burning of crop residue was estimated to account for about 25% of black carbon, organic matter, and carbon monoxide emissions, 9-13 % of PM2.5 and carbon dioxide emissions and about 1% of sulphur dioxide emissions. The authors find that a majority of the fires occurred in the western Indo-Gangetic plain during the months of May and October corresponding to the two major harvesting seasons for rice and wheat. Field burning in major agricultural states such as Punjab, Haryana and Western Uttar Pradesh was the largest potential contributor to these emissions.

Gustafsson et al. (2009) employed radiocarbon analysis (14C) as an atmospheric tracer to measure biomass and fossil-fuel contributions to the South Asian atmospheric brown cloud. They find a much larger contribution of biomass combustion to black carbon emissions (46% for elemental carbon and 68% for soot carbon) than other tracer techniques. Thus, they stipulated that ‘both biomass combustion (such as residential cooking and agricultural burning) and fossil fuel combustion should be targeted to mitigate climate effects and improve air quality.’ Black carbon emissions are the second largest contributors to current global warming followed by carbon dioxide emissions (Ramanathan and Carmichael, 2008). Long et al. (1998) studied the health consequences from burning of agricultural residue. They surveyed 428 participants with underlying respiratory disorders and exposure to pollution from burning of agricultural residue. They find that people with underlying respiratory disorders were susceptible to the air pollution caused by burning of agricultural residue. Underlying symptoms either became worse or additional air pollution related symptoms were induced. In conclusion, biomass combustion needs to be regulated to mitigate these health and climate effects.

This is the first study that uses farm level data to address the regulation of emissions from open field burning of rice residue in Punjab. I conducted surveys in this region to obtain information on the method of residue disposal and its determinants.

I find that the most important determinant of the decision to burn rice residue is the usage of the combine harvester. The decision to use a combine harvester was in turn driven by the type of rice variety sown by the farmer. Farmers that cultivate coarse rice were much more likely to use a combine harvester than farmers that grew Basmati varieties. Unfortunately, combine harvesters are entrenched in the agricultural system of the states of Punjab and Haryana(Erenstein et al., 2007). A modification to the combine harvester can be made enabling the residue to be collected separately. This raises questions about the utilisation of residue. The Happy Seeder technology obviates the need to collect the residue and find alternatives for its use. Happy Seeder is a tractor-mounted machine that cuts and lifts the rice straw, sows wheat into the bare soil and deposits the straw over the sown area as mulch[1]. Wheat can be sown immediately after the rice harvest precluding the need for burning rice residue. But is Happy Seeder a viable alternative to open field burning of rice residue?

I conclude that on average the Happy Seeder technology is cheaper compared to conventional tillage. Furthermore, the difference in the mean yield of the wheat crop was not statistically significant across plots that were cultivated using Happy Seeder or conventional tillage. These are important findings given that emissions from the open field burning of rice residue are the first most contribution to emissions from the open field burning of crop residue in this region(Badarinath et al., 2006).

The finding that mechanised harvesting of cereal crops leads to open field burning of crop residues is in agreement with studies on agricultural field burning elsewhere in the world. Yang et al. (2008)estimate the emissions from crop residue burning in Suqian region located in the Jiangsu province of China. In Suqian, the 'rice-wheat cropping system' is widely practiced. The authors assert that during the period 2001-2005, about 82% of the wheat straw and 32% of the rice straw was burnt in the field. They attribute the open field burning of cereal residues to mechanised harvesting of cereal crops by a combine harvester. However, contrary to Punjab the quantity of crop residue burnt is higher for the wheat crop. This is because June is the busiest month for the farmers of China whereas farmers in Punjab are more hard-pressed during the months of October and December. Another reason is the

[1] A protective cover placed over the soil to retain moisture, reduce erosion, provide nutrients, and suppress weed growth and seed germination.

universal preference for wheat residue as livestock feed by the farmers of Punjab. Thus, wheat residues are vigorously collected and the surpluses traded. Farooq et al. (2007) also associate agricultural residue burning with harvesting of crops by combine harvesters in the Punjab province of Pakistan. There is also widespread use of wheat residue as animal feed in this region. Thus the authors report intensive collection of wheat residue and large scale burning of rice residue. These findings suggest that the Happy Seeder technology has the potential to reduce rice residue burning beyond Indian Punjab.

My results are examined more closely below. The following section describes the sampling design. Section 3 seeks to uncover the factors that explain the field residue burning of rice residue in Punjab. Section 4 analyses the profitability of the Happy Seeder technology and section 5 concludes.

2 Study Area and Sampling

The empirical analysis uses 2 samples, one of users of Happy Seeder and one of non-users of Happy Seeder. Both samples were collected from the state of Punjab[2] because the Happy Seeder technology is so far only available in this state. The list of Happy Seeder users was obtained by contacting the manufacturer of Happy Seeder and various government officials associated with its promotion. I collected data from 92 Happy Seeder users spread across 7 districts of Punjab. Since Happy Seeder is a new technology most users experimented with it on a limited area and simultaneously practised conventional tillage. The data collected included information on yields of the wheat crop and the costs incurred by farmers in preparing the field of the wheat crop using the Happy Seeder technology and conventional tillage.

I conducted another survey to gather similar information from non users of Happy Seeder. I purposively selected the districts of Amritsar, Ludhiana and Sangrur to undertake the survey. I chose these 3 districts because I wanted to capture geographical variation across Punjab. In the second stage, I selected 10 villages for sampling from each of the districts, using the probability proportional to size technique. This technique ensures that farmers in larger villages have the same probability of getting into the sample as farmers in smaller villages and vice-versa. The list of villages was obtained from the 2001 Census of India data. Within a village

[2]In 2006-2007, Punjab was the fourth largest producer of rice and second largest producer of wheat in India, producing 11% of the country's rice output and 19% of its wheat output (Ram, 2008). With rice and wheat yields of 3858 Kg per hectare and 4179 Kg per hectare respectively in 2005-06, the state occupied the top position in the country in terms of food grain yield (Ram, 2008). The ratio of net irrigated area to net area sown stood at 0.95 in 2005-06 and is the highest in the country (Ram, 2008)

voter lists constituted the sampling frame. A voter list assigns a unique household number to each household in a village and specifies the names of all household members who are at least 18 years of age at the time of the preparation of the list. The decision to use the voter list as a sampling frame was taken after conducting a census of a village. The census revealed that the voter list is not grossly distorted. Hence I decided to use the voter list as a sampling frame.

10 households were to be surveyed within each village. Since in each village there would be people who did not engage in any farming activity, I randomly selected 40 households from each voter list. If the first household amongst the 40 households was a farm household it was included in the survey else it was dropped and the second household was contacted. This procedure was followed until the enumerator was able to complete 9 interviews. To see, if farmers with large landholdings behaved differently from farmers with small landholdings, 1 farmer with a large landholding was included in the sample from each village. This was done by asking the respondents to provide names of the 5 largest landowners in their village. I randomly selected 1 farmer from this list for the interview.

I defined a farm household as a group of individuals, related by blood or marriage and living on the same premises, that share a kitchen and practise the rice-wheat cropping system. The respondents to the questionnaire were men who were actively involved in day-to-day farming activity.

Data were collected at plot level as a farm is not one consolidated unit. The total farm area is distributed across plots and farmers follow different practices on different plots. I arrived at the size of a farm unit by summing farm land owned and farmland leased in and subtracting from this total farm land leased out.

These 2 surveys were held between January and April in 2010. I conducted another survey during June 2010 to obtain data on the yield of the wheat crop for all respondents. This survey was conducted by telephonic interview.

3 Determinants of Burning of Rice residue

3.1 Data and Descriptive Statistics

Farmers foremost decide on the rice variety to be sown and the area to be sown to each variety. Rice is a Kharif[3] crop hence it is sown in the months of June-July.

For 90% of the respondents the price and yield of various varieties during the

[3] There are 2 growing seasons in India i.e. Kharif and Rabi. Kharif crops are usually sown with the beginning of rains in June- July, during the south west monsoon season.

previous growing season were the key factors in arriving at this decision. The Food Corporation of India (FCI) procures rice and wheat from the farmers at the minimum support price (MSP) announced by the Government of India. Farmers are free to sell any quantity of grain at this price. The fine grain (Basmati) varieties do not fall under this scheme. The minimum support price was announced in August in 2009 so farmers had to rely on the prices that had prevailed during the previous season. The Food Corporation of India (FCI) further classifies coarse varieties into grade A and common varieties. The minimum support prices for grade A variety and common variety were fixed at 980 Rs per quintal ($21 per quintal) and 950 Rs per quintal ($20 per quintal) respectively in 2009. The fine grain varieties are priced within the range of 2000-3500 Rs per quintal ($43-$75) depending on its quality. During 2008-2009 the price of PUSA 1121 Basmati variety was 2000 Rs ($43) per quintal[4]. This prompted farmers to increase the area sown to this variety in the following season[5]. Consequently, in my sample 75% of the Basmati area was under the PUSA 1121 variety.

21% of the respondents cultivated Basmati varieties and 47% of the respondents cultivated coarse varieties. 32% of the respondents grew both types of varieties.

Figure 1 shows the district-wise distribution of gross cropped area under fine grain (Basmati) and coarse varieties for each of the three districts in my sample.

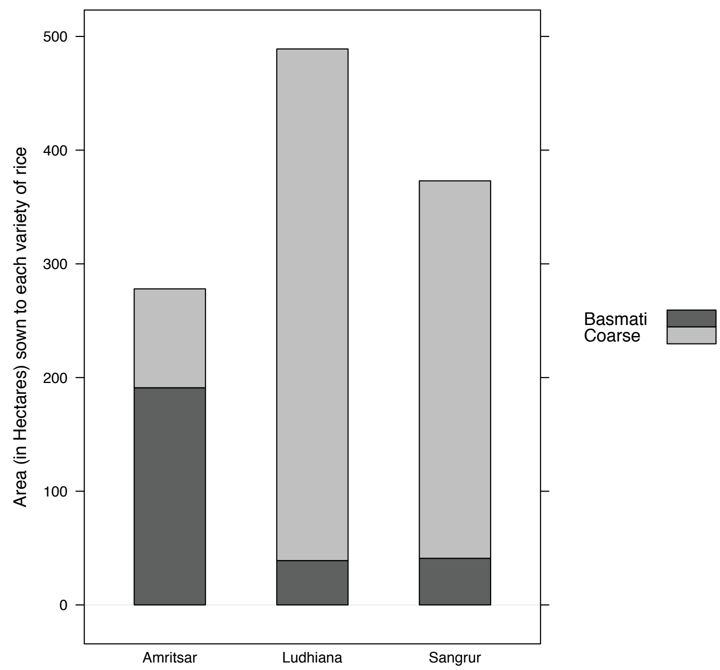
In totality Basmati and coarse varieties were planted on 271 hectares and 869 hectares but there was significant variation across districts. 71% of the gross cropped area sown to Basmati fell in Amritsar and 52% of the gross cropped area sown to coarse variety was situated in Ludhiana. Hence fine grain varieties were predominantly grown in Amritsar. This is because the agro-climatic conditions of this region are conducive to growing Basmati varieties[6]. Consequently, in my sample the most precious Basmati varieties such as 'Super Basmati' are only grown in Amritsar whereas another variety called 'Muchal' is only found in Sangrur.

Figure 1: District wise Distribution of Gross Cropped Area Under Basmati and Non-Basmati Varieties in Punjab, 2010

[4] Source:Amritsar Procurement Centre (Mandi)

[5] Source:Businessworld, 2009 and focus group discussions with farmers.

[6] Source:The Tribune, 2005 and conversations with farmers and agricultural scientists.



There are two choices open to the farmers regards the mode of harvesting i.e. manual harvesting or harvesting by machine (combine harvesters). I find that manual harvesting is popular for the Basmati varieties and particularly for the high quality Basmati varieties grown in Amritsar. This is because use of a combine harvester results in a loss of grain. Given that the price of Basmati rice far exceeds the price of coarse rice, farmers prefer to opt for manual harvesting of Basmati varieties to minimise this loss. Since this price differential is the highest for the most precious Basmati varieties, these varieties are more likely to be harvested manually. Shortage of labour compels many farmers to resort to mechanical harvesting of the relatively low quality Basmati varieties. For similar reasons, farmers did not have any incentive to employ labourers for harvesting coarse varieties. These findings are summarised in Table 2. This table shows that coarse rice varieties were entirely harvested by a combine harvester and Basmati varieties were predominantly harvested by labour.

Table 1:District wise Mean Rental Rate of Combine and Contract Labour during Harvest time of Rice crop in Punjab

District	Mean Rental Rate of Combine Rupees per Hectare (US$ in Parenthesis)	Mean Rental Rate of Contract Labour Rupees per Hectare (US$ in Parenthesis)	Ratio of Mean Rate Labour to Mean Rental Combine
Amritsar	2304	4993	2
	(49)	(105)	
Ludhiana	1621	6871	4
	(35)	(147)	
Sangrur	1619	6378	4
	(35)	(136)	

Notes: The exchange rate used through out the analysis is as on September 7, 2008 i.e. USD 1= INR 46.82

It is also much cheaper and quicker to use combine harvesters than to employ labour. These time savings are dear to the farmers as there is a short time between rice harvesting (mid October-early December) and sowing of wheat November-early December). Any delay in planting reduces the productivity of the wheat crop. As a result combine harvesters are popular with farmers. Table 1 displays the mean rental rate of combine harvesters and contract labour across 3 districts of Punjab. Farmers in Ludhiana save about $112 per hectare by opting for a combine harvester. The corresponding figures for Amritsar and Sangrur are $56 and $102.

I conclude that residue of Basmati variety is used to a larger degree for feeding livestock. 79% of all respondents that fed rice residue to livestock fed the residue of Basmati variety whereas only 17% of such respondents utilised the residue from coarse variety for feeding purposes. 4% of these respondents fed the residue of both varieties to livestock.

I find that the mode of harvesting strongly influences the choice of crop residue disposal. Presently 4 options are available to the farmers for disposal of residue namely complete burning of residue, partial burning of residue, incorporation of residue and removal of the residue from the field. The combine harvester leaves two types of residue on the field, loose residue and intact residue. Intact residue is the stalk of the rice plant that is left standing in the field after the combine machine has cut the top most portion of the plant that carries the grain. Its height varies from 8 to 10 inches. Loose residue is the residue that is scattered by the combine harvester after the harvesting and threshing of the rice crop. This part of the residue is hard to retrieve as it is unevenly distributed over the field. Complete burning involves burning loose and intact residue. Partial burning involves burning loose residue only.

Table 2

Variety of Rice - Basmati				
	Mode of harvesting			
	Manual		Combine	
Method of disposal	% of the Area Sown to Basmati that is harvested using Labour	No. of Hectares	% of the Area Sown to Basmati that is harvested using Combine	No. of Hectares
Fully Burnt	1	2	57	53
Partially Burnt	0	0	16	15
Incorporated	0	0	18	17
Removed	99	175	9	9
Variety of Rice - Coarse				
Fully Burnt	0	0	76	657
Partially Burnt	0	0	16	141
Incorporated	0	0	4	33
Removed	0	0	4	38

As Table 2 shows, rice residue from 2 hectares was burnt after manual harvesting while residue from 866 hectares was burnt post harvesting by a combine machine. Residue of Basmati varieties that are hand harvested was sought after as 99% of this residue was cleared from the field. In contrast, rice residue left by the combine harvester was largely burnt irrespective of the type of variety of rice grown. Incorporation of the rice residue into the field was mainly practiced in Amritsar due to the stringent ban on burning of rice residue in Amritsar.

3.2 Model and Results

Let b=1 denote burning of residue and b=0 otherwise. Likewise c=1 denotes usage of a combine machine and 'c=0' otherwise. Let b^* be an unobserved, or latent variable, determined by

$$b^* = x_b'\beta_b + \epsilon_b \qquad and \quad b = \begin{cases} 1 & \text{if} \quad b^* \geq 0 \\ 0 & \text{otherwise} \end{cases}$$

where x_b' is a vector of farmer specific attributes, (e.g. age, education, farm size etc.), and ϵ_b is a disturbance term having a zero mean. The i^{th} farmer will choose to burn residue on the p^{th} plot if

$$\begin{aligned} Pr[b = 1|x] &= Pr[b^* > 0|x] \\ &= Pr[x_{ib}'\beta_b + \epsilon_{ib} > 0|x] \\ &= \Pr[\epsilon_{ib} > -(x_{ib}'\beta_b)|x] \\ &= 1 - F[-x_{ib}'\beta_b] \end{aligned}$$

where F is the cumulative distribution function of ϵ_{ib} and ϵ_{ib} is independent of $x_{ib}'\beta_b$.

The functional form of F will depend on the assumptions made about ϵ_b. A probit model arises from assuming that ϵ_b is normally distributed with a unit variance.Then F is the standard normal cumulative distribution function Φ. Thus, for a farmer 'i', the probability of burning rice residue and using a combine machine, respectively, is given by:

$$\begin{aligned} Pr[b = 1|x] &= \Phi[x_{ib}'\beta_b] \\ Pr[c = 1|x] &= \Phi[x_{ic}'\beta_c] \end{aligned}$$

The two equations can be estimated consistently by single equation probit methods. But in my model, one of the important covariates in the equation of burning, the mode of harvesting, is likely to be jointly determined with the burning indicator. As the preceding section illustrates, Basmati varieties were more likely to be harvested manually. Since manual harvesting allows for easy retrieval of the rice residue, this residue is less likely to be burnt. Thus, farmers simultaneously decide on the mode of harvesting and the method of residue disposal. A single equation probit method is inefficient in that it ignores the possibility of correlation between the disturbances ϵ_b and ϵ_c in the underlying latent variable models(Greene, 1998). In this case, the disturbances have a bivariate normal distribution and these equations should be estimated using a bivariate probit model (Greene, 1998).

The bivariate probit model considers two binary outcomes that are potentially related via correlation of errors that appear in the underlying latent variable models.

The recursive bivariate probit model is a slight modification of the basic bivariate probit model with c appearing on the right hand side of the equation of b^* such that

$$
\begin{aligned}
b^* &= x_b'\beta_b + c\gamma + \epsilon_b \\
c^* &= x_c'\beta_c + \epsilon_c \\
E[\epsilon_b|x_b, x_c] &= E[\epsilon_c|x_b, x_c] = 0 \\
Var[\epsilon_b|x_b, x_c] &= Var[\epsilon_c|x_b, x_c] = 1 \\
Covar[\epsilon_b, \epsilon_c|x_b, x_c] &= \rho
\end{aligned}
$$

We observe the two binary outcomes

$$
b = \begin{cases} 1 & \text{if} \quad b^* \geq 0 \\ 0 & \text{otherwise} \end{cases} \qquad \textit{and} \qquad c = \begin{cases} 1 & \text{if} \quad c^* \geq 0 \\ 0 & \text{otherwise} \end{cases}
$$

The model collapses to two separate probit models for b and c if $\rho = 0$ because when ρ is zero, the covariance between ϵ_b and ϵ_c equals zero. The most suitable technique of estimating a bivariate probit model is full information maximum likelihood.

It turns out, that despite the issue of endogeneity the terms that enter the likelihood of the recursive bivariate probit model are the same as those for the usual bivariate probit model (Greene, 1998).

Furthermore, Wilde (2000) has shown that identification by functional form is present in the recursive bivariate probit model in the absence of exclusion restrictions. However, the common practice is to impose restrictions to improve the identification of the model. In my model, the rice variety sown by a farmer serves to identify the predicted value of c in the equation of burning. This is because the rice variety sown affects the method of residue disposal through its impact on the mode of harvesting. Once the choice of the mode of harvesting is made the rice variety sown plays no role in determining the method of residue disposal. Table 2 shows that after manual harvesting of the rice crop, the rice residue was by and large removed from the field. On the other hand, rice residue that was left behind by the combine harvester was mostly burnt irrespective of the rice variety sown. Incorporation of the rice stubble into the fields for both varieties was predominant in Amritsar due to the prohibition on burning rice residue in this region. The residue was removed from a small area owing to extraneous reasons such as presence of the landless ‘Gujjar’ community that collected the residue for free for feeding livestock.

The absence of the reaper harvesting technology in rice further reflects the very limited use of rice residue that remains on the field after harvesting of the rice plant by a combine harvester. This technology is in widespread use for the wheat crop. It harvests the wheat residue left in the field by the combine harvester by chopping it so that it can be used as fodder for livestock. As mentioned earlier, wheat residues have a scarcity value and the surpluses are traded. By contrast, there is no market for rice residue in Punjab.

The variables used in this study to explain the choice of the method of residue disposal and the mode of harvesting come out of the profit maximising exercise of the farmer. Although I do not model profits explicitly, the discussion in the preceding section seeks to motivate which heterogeneous characteristics of farmers and their growing conditions influences their choice of harvesting and residue disposal. This discussion implies that the mode of harvesting, location, age of the farmer, education of the farmer, technical ability of the farmer, scale of operation and family size explain the choice of the method of residue disposal. Small scale farmers may be more inclined to remove the residue from the fields for feeding livestock. The raw data in fact suggests that small scale farmers are more likely to remove the residue from their fields.

The dependent variables in the equation of mode of harvesting are the rice variety sown by the farmer on a plot, scale of operation, ownership of livestock, family size, rental rate of a combine harvester in the village, rental rate of contract labour in the village, age and education of the farmer, technical ability of the farmer and farm location. The discussion in the preceding section indicates that the rice variety sown has implications for the mode of harvesting (manual or combine). Small-scale farmers may be more inclined to use their own labour or employ labour for harvesting of Basmati varieties. Farmers who own livestock are more likely to harvest the crop manually. I allowed for this effect to vary with the rice variety sown as farmers have a preference for the residue of Basmati variety for feeding livestock. Farm location may influence the mode of harvest even after controlling for the rice variety sown. This is because farmers in Amritsar plant high quality Basmati varieties that are more likely to be harvested manually.

The method of residue disposal may influence the choice of the method of harvesting. However, this influence is not important enough given that there is no market for rice residue in Punjab. Thus, in terms of profits the residue disposal decision is not as important as the choice of the mode of harvest. Hence, I do not control for the method of residue disposal in the equation of the mode of harvesting.

The mode of harvesting is captured by introducing a dummy variable that equals 1 if the farmer used a combine harvester to harvest the rice crop on a plot and 0 otherwise. The binary variable Coarse identifies the rice variety sown on a plot and it equals 1 if the variety of rice sown on a plot is coarse and 0 otherwise. Such a variable is assumed to be exogenous as the decision to sow a particular variety is primarily driven by its price during the previous season. Given the prices and the favourable agro-climatic conditions, farmers in Amritsar find it profitable to cultivate Basmati varieties. Another justification for this assumption is provided in section 3.4. Family size is proxied by the number of family members equal to or above 15 years of age in the household per hectare of farm area sown to rice. Ownership of livestock is reflected by the number of livestock owned per hectare of farm area. The availability of human capital is indicated by years of education of the farmer. Innovativeness and technical ability of the farmer were proxied by the viewer-ship of a television programme related to farming, contact with extension services and whether the farmer read agricultural magazines. The effect of the scale of operation is captured by farm size. Location is represented by the dummy variable Amritsar that equals 1 if the plot is located in Amritsar and 0 otherwise.

The descriptive statistics of the variables included in the analysis are given in Table 3.

Table 3 : Description of the variables used in the analysis

Variables	Description	Unit of Measurement	Variables	
			Mean	S.D.
Burnt	Indexes the method of residue disposal on a plot. 1= residue is burnt ,0 otherwise	% of Plots	0.64	0.48
Combine	Whether or not farmer used a Combine to harvest rice on a plot. 1= Combine machine is used ,0=otherwise	Number of Plots	0.74	0.44
Coarse	Type of variety of rice sown by the farmer on a plot. 1=coarse,0=Basmati	Number of Plots	0.64	0.48
Farm Size	Size of a farm unit	Hectares	5.03	5.51
Number of livestock per hectare of farm area		Number	2.46	1.96
Watch	Whether or not farmer watched a television programme on farming. 1=Watches,0=Does not watch	Number of Farmers	0.56	0.50
Contact with Extension	Whether or not an extension agent visited the farmer in the year preceding the survey 1=Yes,0=No	Number of Farmers	0.24	0.43
Reads Magazines	Does the farmer read agricultural magazines. 1=Yes,0=No	Number of Farmers	0.20	0.40
Age of the farmer		Number	51.73	14.21
Education of the farmer		Number	8.16	4.1
Number of persons equal to or above 15 years of age in the household per hectare of farm area sown to rice		Number	2.71	2.91
Rental rate of Combine Harvester in Village		Rupees per Hectare	765 ($16.34)	161.97
Rental rate of Contract Labour in Village		Rupees per Hectare	2381.67 ($50.84)	591.39
Amritsar	Dummy Variable that equals 1 if a plot is located in Amritsar,0 otherwise	Number of Plots	0.32	0.47
Number of Plots	Number of plots in the sample	Number	604	
Number of Farmers	Number of farmers in the sample	Number	268	

Notes: Since 1 farmer with a large landholding was purposively included in the survey from each village, these farmers were omitted from the calculation of the summary statistics. However, in the first 2 villages 2 farmers with large landholdings were erroneously included in the study.

3.3 Discussion Of Results

I estimated the recursive bivariate probit model using maximum likelihood as the estimation criterion. I corrected the standard errors for clustering at the farmer level. The estimated value of rho was -0.16. The t ratio on this coefficient was -0.86 suggesting that the unobservables may be uncorrelated. The likelihood ratio test of the null hypothesis that rho equals zero against the alternative that rho does not equal zero showed that the null hypothesis that the covariance parameter $\rho = 0$ was not rejected at the 39% significance level, indicating the validity of estimating the two equations separately. This is not surprising. The correlation coefficient measures the correlation between the outcomes after the influence of the explanatory variables is accounted for. Thus, the value, -0.16 measures the effect of unobservables after the influence of using a combine harvester is already accounted for. However, as discussed later on, the single most important determinant of whether the residue on a plot will be burnt is indeed whether a combine harvester is being used to harvest the rice crop on the plot. Hence I estimated each equation using single equation probit methods.

3.4 Determinants of Mode of Harvesting

The most important factor affecting the choice of mode of residue disposal was the variety of rice sown by a farmer (Column 1, Table 4). This was expected given the statistics in Table 2. On plots that were planted with coarse varieties, on average, farmers were 63% more likely to use combine harvesters. The number of livestock owned per hectare of farm area had a small impact on the decision of the mode of harvesting. The average change in the predicted conditional probability that combine equals 1 for a 1 unit increase in livestock per hectare of farm area differed between coarse and Basmati varieties by 7% points, with coarse rice growers having higher marginal effects on livestock on average. Farmers in Amritsar on average were significanltly less likely to use a combine harvester. This reflects farmer's preferences for manual harvesting of the high quality Basmati varieties in this region. It is noteworthy that the variable Amritsar turned out to be statistically insignificant when I computed the marginal effects fixing the values of the variables Coarse and Amritsar at 1 and keeping all the other variables fixed at their mean values. This shows that plot location was of no consequence to the mode of harvesting for coarse varieties. The location variable Amritsar was statistically significant in the regression that excluded the variable Coarse. The average partial effect of the variable

Amritsar increased to -0.39. This is because the effect of the variable Coarse was being picked up by the variable Amritsar. Since location of a farmer can be assumed to be exogenous at a given point in time, the variety of rice sown by a farmer can also be assumed to be exogenous. To see this more closely, I ran 2 separate regressions for each of the varieties using a linear probability model with village fixed effects. As predicted, Amritsar was statistically significant in the regression for the Basmati variety and insignificant in the regression for the coarse variety. Like in the probit model the location dummy Amritsar was significant in the regression that excluded the variable Coarse.

The model predicted 91% of the plots on which a combine harvester was being used correctly, and 91% of the plots on which manual labour was being used correctly, with an overall correct prediction rate of 91%.

As a robustness check, I estimated this model using a linear probability framework with farmer fixed effects and village fixed effects . The results are reported in columns 2-3 of Table 4. These results are consistent with the results in column 1.

Table 4 : Marginal effects of the variables on choice of harvesting in Punjab: 2010

Variables	probit method (Average Marginal Effect)	farmer fixed effect (Marginal Effect)	village fixed effect (Marginal Effect)
Coarse	.6275***	.5036***	.5123***
	(17.98)	(8.38)	(7.42)
Number of Livestock	-.0254***	–	-0.0535***
	(-2.75)	–	
Number of Livestock*Coarse	.0710**	.0669***	.0537***
	(2.33)	(3.46)	(3.07)
Farm Size	.0009	–	.00103
	(0.48)	–	(0.55)
Number of persons equal to or above 15 years of age in the household	.0226	–	.00009
	(0.42)	–	(0.01)
Rental rate of Contract Labour in village	-.0007***	–	–
	(-3.42)	–	–
Rental rate of Combine Harvester in Village	-.0001	–	–
	(-1.44)	–	–
Watch	-.0008	–	-.00009
	(-0.03)	–	(-0.00)
Contact with Extension	.0374	–	.0193
	(1.51)	–	(0.76)
Reads Magazines	-.0689***	–	-.0421
	(-2.95)	–	(-1.53)
Age of Farmer	.0016**	–	.0019*
	(2.23)	–	(1.92)
Education of Farmer	.0013	–	.0017
	(0.40)	–	(0.46)
Amritsar	-.1191***	–	–
	(-3.34)	–	–
Number of Plots	736	736	736
Number of Farmers	300	300	300
Log Likelihood	-151.01	–	–
R Squared	–	0.51	0.49

Notes: Dependent variable is Combine, Combine=1 if the farmer used a combine harvester on a plot and 0 otherwise. Figures in parenthesis are t-ratios. For probit regression the standard errors are clustered at the farmer level and robust standard errors are reported for the farmer and village fixed effects. *** indicates significance at the 1% level, ** indicates significance at the 5% level, * indicates significance at the 10% level.

Table 5 shows the strong effect on the usage of a combine harvester of growing coarse varieties and how this effect varies by location and technical ability of the farmers. A farmer was assumed to be technically able if he watched the televised programme on farming, read agricultural magazines and had been contacted by an extension agent in the year prior to the survey. Farmers that did not meet any of these criteria were not assumed to be technically able. The last column in the table shows the difference in the predicted probabilities for each corresponding row. None of these differences turned out to be statistically significant implying that there were no differences in outcomes for farmers that were not technically able and for farmers that were technically able.

Table 5

Variety	Location	Predicted Probability of using a Combine Harvester		
		Technically Able	Not Technically Able	Difference
Coarse	Amritsar	.97	.99	.02
	Not Amritsar	.9977	.9992	.002
Basmati	Amritsar	.13	.21	.08
	Not Amritsar	.42	.55	.13

Notes: The predicted probabilities were calculating fixing all the other variables at their means.

3.5 Determinants of Method of Residue Disposal

Table 6 : Marginal effects of the variables on choice of residue disposal in Punjab: 2010

Variables	probit method (Average Marginal Effect)	farmer fixed effect (Marginal Effect)	village fixed effect (Marginal Effect)
Combine	.7960***	.7747***	.7102***
	(27.26)	(18.19)	(14.48)
Farm Size	-.0009	–	.0020
	(-0.34)	–	(0.65)
Number of Persons equal to or above 15 years of age in the household	-.0175*	– 0	-.0202**
	(-1.92)	–	(-2.20)
Watch	-.0098	–	-.0122
	(-0.37)	–	(-0.40)
Contact with Extension	.0084	–	-.0147
	(0.28)	–	(-0.62)
Reads Magazines	-.0417	–	-.0537*
	(-1.23)	–	(-1.75)
Age of Farmer	.0012	–	.0012
	(1.22)	–	(1.38)
Education of Farmer	-.0002	–	-.0022
	(-0.05)	–	(-0.58)
Amritsar	-.2332***	–	–
	(-4.79)	–	–
Number of Plots	736	736	736
Number of Farmers	300	300	300
Log Likelihood	-190.957	–	–
R Squared	–	0.70	0.50

Notes: Dependent variable is Burnt, Burnt=1 if the farmer burnt residue on a plot and 0 otherwise. Figures in parenthesis are t-ratios. For probit regression the standard errors are clustered at the farmer level and robust standard errors are reported for the farmer and village fixed effects. *** indicates significance at the 1% level, ** indicates significance at the 5% level, * indicates significance at the 10% level.

The average marginal effects of the variables in the equation of method of residue disposal are shown in column 1 of Table 6. Results of the method of residue disposal model indicated that the model successfully predicted 99% of all plots on which the rice residue was burnt, and 74% of all plots on which the residue was not burnt, with an overall correct prediction rate of 90%.

By far, the most substantial effect, on average, on the probability that the residue will be burnt on a plot was exerted by the usage of a combine harvester. Residue on plots on which the rice crop was harvested using a combine harvester was on average 80% more likely to be burnt than residue on plots on which farmers harvested the rice plant using farm labour. Another factor influencing the decision to burn the residue was farm location. Plots located in Amrtisar[7] on an average were 24% less likely to get burnt than plots situated in Ludhiana and Sangrur. Farm size, age of the farmer and availability of human capital did not appear to have influenced the decision to burn rice residue. These findings are consistent with the results obtained from the models that include farmer fixed effects and village fixed effects (Columns 2-3 of Table 6).

Table 7

Method of Harvest	Location	Predicted Probability of Burning		
		Technically Able	Not Technically Able	Difference
Combine	Amritsar	.55	.66	.11
	Not Amritsar	.91	.95	.04
Manual	Amritsar	.001	.002	.001
	Not Amritsar	.02	.04	.02

Notes: The predicted probabilities were calculating fixing all the other variables at their means.

Table 7 is analogous to Table 5. It shows that farmers that were technically able and that used a combine harvester had a lower probability of burning rice residue. This difference was more pronounced in district Amritsar. However, it did not turn out to be statistically significant. The predicted probability of burning rice residue was virtually nil for plots that were harvested manually.

[7]The data suggested that some farmers may not have truthfully revealed their method of residue disposal. Hence as a robustness check, I estimated these models assuming that these farmers had burnt the residue. The results did not change on account of this assumption.

3.6 Policy Options

My results imply that the most important determinant of the decision to burn rice residue is the usage of a combine harvester. I find that burning of residue is less pronounced in the district of Amritsar. However, these farmers did not have an incentive to truthfully reveal their method of residue disposal. Hence the estimate obtained above is an upper bound of the effectiveness of the prohibition ob burning rice residue in this region. Thus, if a ban on burning rice residue is implemented all across Punjab it will not be successful in mitigating burning of agricultural field residue.

Unfortunately, the usage of a combine harvester is not amenable to policy intervention. The advantages combine harvesters offer in terms of savings of money and time and reduced supervision of labour have made them immensely popular with the farmers. Presently combine harvesters are being mainly used to harvest coarse varieties in Punjab but as the discussion in section 4 shows farmers who face labour scarcity resort to mechanical harvesting of the Basmati varieties. Thus, in the advent of increased labour scarcity, use of combine harvesters is likely to spread.

Given that rice residue are of limited value to the farmers both as livestock feed and non-feed use[8], it needs to be seen whether rice residue can be fruitfully used outside the agricultural sector. Balers have been introduced in the district of Amritsar and the baled residue is being used to generate electricity in a sugar mill in this district. However, baling of residue may not be a viable mitigation strategy as the supply of baled residue may outweigh its demand. There is no data available on the quantities of residue demanded by the various industries in Punjab and the quantities supplied to substantiate this claim.

Another viable alternative is encouraging development of machines that allow farmers to plant wheat into the loose residue. The Happy Seeder technology performs this function in the context of rice residue. Thus, an important research question is whether the Happy Seeder technology is a viable alternative to open field burning of rice residue. I have addressed this question in the subsequent section.

4 Development of the Happy Seeder Technology

Engineers of CSIRO Griffith at Punjab Agricultural University developed the first prototype of Happy seeder in India in July 2001. The machine consisted of a stan-

[8]Composting is costly and will not be undertaken by farmers unless they are compelled to do it

dard Indian Seed drill with inverted T-boots attached by three-point linkage behind a forage harvester with a modified chute. Although preliminary tests of this technology with about 6 t/ha of anchored and loose rice residue were very encouraging, in some situations establishment of the wheat crop was poor. To deal with this problem the Happy Seeder technology was modified in 2004. A narrow strip tillage assembly was added in front of the sowing tynes to improve the contact of the seed with the soil. However, problems persisted with this technology and it was again modified in 2005 and 2006. At the time of the field survey Happy Seeder was being manufactured by 1 manufacturer at Ramdass in the district of Gurdaspur in Punjab. This technology was first sold to a farmer in this district in 2007[9]. Till date the Happy Seeder technology is undergoing modifications in its design and is being tested for its performance.

4.1 Comparison of Profits across users and non users of Happy Seeder

4.2 Conceptual Framework

Since the price of wheat is fixed by the Government of India, the usage of Happy Seeder can affect revenue from wheat production by affecting its yield. To determine the impact of Happy Seeder technology vis-a-vis conventional tillage on yield per hectare of wheat sown, I estimated regressions that included farmer fixed effects. I used plot level data collected from the users of Happy Seeder for conducting these regressions. As mentioned before most farmers used Happy Seeder on a limited area while simultaneously using conventional tillage thereby allowing me to control for farmer fixed effects. Farmer fixed effects net out any unobservable factors among farmers that might simultaneously affect yield and the performance of the Happy Seeder technology. Therefore, variations in the performance of the Happy Seeder technology were natural variations in the functioning of the Happy Seeder technology. I exploited this heterogeneity to estimate the effect of interest.

The explanatory variables include a set of plot level and farmer level characteristics (the size of the plot, soil type, quantity of fertilizers applied to a plot, age and education of the farmer and variables that measure the technical ability of the farmer such as whether the farmer watched a television programme related to farming), and a binary variable named Happy Seeder that equals 1 if the wheat crop on a plot was sown using Happy Seeder technology and 0 otherwise.

It is not possible to control for the mode of irrigation as all the farmers in the

[9] Source: Manufacturer of Happy Seeder

sample use a tube well for irrigation. Electricity is given for free to the farming sector in Punjab and so farmers are unable to provide information on the expenditure incurred on irrigation or the quantity of water used for irrigation. The effect of quantity of water used for irrigation, however, is captured by the farmer fixed effect.

For the coefficient on the Happy Seeder variable to have a causal interpretation, the unobserved determinant of yield must be uncorrelated with the Happy Seeder variable. Since any potential confounding farmer level characteristics are included for by farmer fixed effects, any correlation between yield and the treatment variable must be on account of unobserved plot level characteristics. If type of wheat variety sown on a plot affects yield and correlates with the Happy Seeder variable, the estimated coefficient on the Happy Seeder variable will be biased. I regressed yield per hectare of wheat on variety of wheat sown to determine if different varieties significantly produced different yields. Focus group discussions with farmers suggest that the yield of wheat is not significantly affected by type of wheat variety sown. The yields can be expected to differ at most by a magnitude of 1-2 quintals across varieties. I find that 2 varieties that were significant at the 10% level produced yields that exceeded this margin. These varieties were grown by a handful of farmers. It may be that few farmers had access to some new varieties that under or over perform relative to widespread varieties. To rule out the possibility of correlation between type of variety sown by a farmer and the Happy Seeder variable, I controlled for these 2 varieties in the yield and profit regressions. There may also be a plot-specific selection effect as farmers may choose to use Happy Seeder on plots that they believe are more suited for this technology. I control for the type of soil on a plot to account for this effect. Besides, Happy Seeder is a new technology hence farmers may not be aware of the plot characteristics that are appropriate for this technology. Hence plot selection can be assumed to be random.

The seedlings of the wheat crop can be planted manually or by machines. The seeding of a crop into unploughed fields is called zero-tillage or no tillage. Besides Happy Seeder some other machines have been developed that can grow zero-tillage wheat. Although zero-tillage depends on the use of a zero-tillage seed drill, farmers in Punjab use zero-tillage seed drills on conventionally tilled fields. Hence I treat sowing of the wheat crop by zero-tillage seed drill as conventional tillage. Another tillage system involves the use of a tractor-drawn Rotavator. Rotavator is typically used after burning the loose rice residue. It involves a single pass of shallow intensive tillage that incorporates the anchored residue and pulverises the soil. Rotavator is a recent introduction in the agricultural system of Punjab but I will treat it as conventional tillage as its usage involves burning of residue and tillage.

Finally, conventional tillage for wheat implies burning of the rice residue followed by multiple passes of the tractor to accomplish ploughing, harrowing, raking and seeding operations.

The second question that I investigate in this section is whether the Happy Seeder technology was a low or high cost alternative to conventional tillage. For this purpose, I estimate regressions with cost incurred per hectare in establishing the wheat crop as the dependent variable. The explanatory variables in these regressions include the controls in the yield regressions and the output of the wheat crop on a plot and the mean price per kg of fertilizer paid by the farmer.

9 respondents had purchased the Happy Seeder technology and consequently did not incur any expenditure on hiring it. They were assigned the average cost of using Happy Seeder that prevailed in their district.

A prerequisite of using Happy Seeder is that the loose rice straw left by the combine harvester should be spread uniformly on the field. Mostly farmers employed labour for spreading this residue but combine harvesters that have a spreader attached to them have also been developed. In addition, farmers incurred expenditure on the purchase and application of weedicide and fertilizers. Farmers who had used their own labour for applying weedicide or for spreading the loose residue were assigned the prevailing wage rate in their village[10] of applying the same.

The cost per hectare of preparing the field using Happy Seeder comprised the cost of hiring Happy Seeder, the diesel expenses incurred, if any on operating it, the amount spent on spreading the residue and application of weedicide, as well as the amount spent on purchasing fertilizers and weedicide.

As with the Happy Seeder technology, the total cost per hectare of establishing wheat with conventional tillage comprised the cost of hiring farm equipment and the diesel expenses incurred, if any on operating it, and the amount spent on the purchase and application of weedicide and fertilizers. For the owners of farm machinery, I imputed a value of the service cost of farm equipment based on the village rental of this equipment.

Next, I estimate regressions with profit per hectare from wheat production as the dependent variable to see whether the Happy Seeder technology was a profitable alternative to conventional tillage. The controls in these regressions are similar to the controls in the cost regression except that I do not control for the yield of the wheat crop. The descriptive statistics of the variables used in the analysis are given

[10]If village level rates were not available the district level estimates were used for imputing these rates.

in Table 8.

Table 8 : Description of the variables used in the analysis

Variables	Description	Unit	Means (Standard Deviation in Parenthesis)		
			Plots sown with Conventional Tillage	Plots sown using Happy Seeder	Entire Sample
Yield per hectare	Quantity of wheat produced per hectare on a plot	Quintals	43.81 (4.317)	43.31 (6.193)	43.57 (5.286)
Cost per hectare	Per hectare expenditure incurred on preparing the field of wheat	INR	7288.54 (2657.56)	6225.3 (1235.1)	6780.32 (2161.80)
Profit per hectare	Per hectare profit earned from wheat production	INR	40024.4 (5318.05)	40548.27 (6644.97)	40274.81 (5975.51)
Happy Seeder	Whether or not farmer used Happy Seeder to sow wheat on a plot 1= Happy Seeder is used ,0=otherwise	No. of plots	—	—	(0.48) (0.50)
Plot Size	Size of a plot	Hectares	6.039 (5.760)	5.342 (5.630)	5.706 (5.691)
Fertilizer	Quantity of fertilizers applied per hectare of wheat	Kg	473.09 (87.88)	461.00 (97.09)	467.28 (92.30)
Price of Fertilizer	Mean price of fertilizers	Price per Kg	–	–	7.14 (0.28)
Age	Age of farmer	No. of farmers	48.92 (13.08)	49.83 (12.45)	49.35 (12.75)
Education	Years of Education of Farmer	No. of farmers	10.30 (2.67)	10.05 (3.27)	10.18 (2.96)
Watch	Whether or not farmer watched a television programme on farming 1=Watches,0=Does not watch	No. of farmers	0.57 (0.50)	0.59 (0.50)	0.58 (0.50)
Contact with Extension	Whether or not an extension agent visited the farmer in the year preceding the survey 1=Yes,0=No	No. of farmers	0.69 (0.47)	0.65 (0.48)	0.67 (0.47)
Reads Magazines	Does the farmer read agricultural magazines. 1=Yes,0=No	No. of farmers	0.48 (0.50)	0.49 (0.50)	0.48 (0.50)
Number of Plots	Number of plots in the sample	No.	83	76	159
Number of Farmers	Number of farmers in the sample	No.	66	66	66

Notes : The Happy Seeder technology was made available to 22 respondents free of cost whereas 1 farmer could not be contacted for obtaining the data on the yield of the wheat crop. 3 farmers burnt the rice stubble prior to using Happy Seeder. This reduced the sample size to 66 farmers for the profitability analysis. I do not report the descriptive statistics for soil type and type of variety of wheat sown for the sake of brevity.

4.3 Empirical Results

Table 9 contains estimates of the effect of Happy Seeder technology on yield per hectare, cost per hectare and profit per hectare of wheat sown on a plot. In columns 1 to 3, I report the results of the regression model that has yield per hectare as the dependent variable. Column 1 shows the results of the random-effects model fitting them by generalised least squares. The coefficient on the Happy seeder variable was negative (though small in magnitude) and insignificant implying that the use of Happy Seeder did not impact the yield of the wheat crop. The results in column 2 of Table 8 are estimates of the farmer-fixed effects model. I continued to find that Happy Seeder had no impact on the yield of the wheat crop. Column 3 presents the results of the pooled least squares estimation. The least squares results also imply that the Happy Seeder technology had no effect on the output of the wheat crop relative to conventional tillage.

Columns 4 to 6 display the results of the equation with cost incurred per hectare on preparing the field of wheat as the dependent variable. The results from all the models (Column 5) indicate that on average the Happy Seeder technology was a low-cost alternative vis-a-vis conventional tillage. The cost saving is highest in the fixed-effects model. Since the fixed-effects model controls for confounding factors at the farmer level, this result strongly indicates that amongst the users of the Happy Seeder technology, on average, plots that were sown using Happy Seeder were prepared at a lower cost to the farmers compared to plots that were sown with conventional tillage. aThis cost saving amounted to 1000 Rs (21$).

In columns 7 to 9, I present the results of the model that estimates the effect of Happy Seeder technology on profitability. I do not find that on average Happy Seeder is a more profitable alternative to conventional tillage and this finding is consistent across specifications.

These findings, however, are applicable to the users of the Happy Seeder technology. In order to assess whether this technology can be profitably used by non users of Happy Seeder, I compared the means of farm characteristics between the two samples in my study.

Table 9 : Estimates of Yield, Cost and Profit per hectare from wheat production in Punjab in 2009-2010

Variables	Yield per Hectare			Cost per Hectare			Profit per Hectare		
	RE (1)	FE (2)	POLS (3)	RE (4)	FE (5)	POLS (6)	RE (7)	FE (8)	POLS (9)
Happy Seeder	-0.261 (-0.32)	-0.920 (-1.08)	0.113 (0.13)	-980.4*** (-2.93)	-1027.5*** (-3.21)	-922.5**** (-2.39)	968.3 (0.99)	968.5 (0.95)	1013.3 (1.03)
Yield per Hectare	–	–	–	12.63 (0.43)	7.617 (0.17)	15.40 (0.55)	–		
Plot Size	0.0949** (2.09)	0.0290 (0.58)	0.132*** (2.69)	29.13 (1.51)	-31.20 (-1.63)	93.38*** (3.52)	2.868 (0.05)	38.22 (0.88)	-35.00 (-0.50)
Fertilizer	0.0736 (1.34)	-0.00296 (-0.04)	0.0828 (1.53)	–	–	–			
Fertilizer Squared	-0.00009 (-1.57)	-0.00003 (-0.42)	-0.0001* (-1.71	–	–	–			
Price of Fertilizer	–	–	–	272.7 (0.93)	–	354.2 (1.16)	-2536.3*** (-4.23)	–	-2417.3*** (-3.51)
Age	0.002 (0.05)	–	0.0123 (0.33)	-7.065 (-0.42	–	-11.11 (-0.54)	51.67 (1.07)	–	56.08 (1.19)
Education	-0.385* (-1.78)	–	-0.400* (-1.90)	-3.282 (-0.07)	–	-17.21 (-0.31)	-124.1 (-0.63)	–	-109.4 (-0.55)
Watch	0.651 (0.57)	–	0.0558 (0.05)	351.3 (0.85)	–	177.5 (0.35)	-1807.0 (-1.50)	–	-2085.7* (-1.79)
Contact with Extension	-1.543 (-1.23)	–	-1.401 (-1.17)	232.7 (0.55)	–	338.4 (0.64)	-441.6 (-0.37)	–	-557.7 (-0.46)
Reads Magazines	-0.738 (-0.62)	–	-0.889 (-0.61)	-153.9 (-0.32)	–	-404.0 (-0.72)	-475.1 (-0.37)	–	-57.16 (-0.05)

Notes: The dependent variable in column 1 to 3 is yield per hectare of wheat on a plot. The dependent variable in column 3 to 6 is cost incurred per hectare (in INR) on field preparation of wheat on a plot.The dependent variable in column 7 to 9 is per hectare profit earned (in INR) from wheat production on a plot. Figures in parenthesis are t-ratios. For OLS regressions the standard errors are clustered at the farmer level and robust standard errors are reported for the farmer fixed and random effects. The coefficients on the soil type, variety of wheat sown are not reported for the sake of brevity. *** indicates significance at the 1% level, ** indicates significance at the 5% level, * indicates significance at the 10% level.

Table 10 : Descriptive Statistics and Mean Differences Between the plots of Users and Non-Users of Happy Seeder

	Means, sample of plots cultivated using conventional tillage by non-users of Happy Seeder	Means, sample of plots cultivated using conventional tillage by users of Happy Seeder	Means, sample of plots cultivated using Happy Seeder by users of Happy Seeder	T-test, differences between means in column 1 and column 2	T-test, differences between means in column 1 and column 3	T-test differences between means in column 2 and column 3
	(1)	(2)	(3)	(4)	(5)	(6)
Characteristics						
Yield Per Hectare	43.84 (0.269)	43.67 (0.468)	43.65 (0.736)	0.169 (0.566)	0.194 (0.662)	0.025 (0.844)
Quanity of Fertilizer applied per hectare	505.31 (4.80)	472.91 (7.92)	456.86 (9.22)	32.40*** (10.02)	48.45*** (10.94)	16.05 (12.08)
Per Hectare Expenditure on Weedicide	1115.09 (19.97)	980.73 (33.54)	899.39 (47.13)	134.37*** (41.66)	215.71*** (47.23)	81.33 (56.24)
Number of Plots	438	122	101			
Number of Farmers	267	70	88			

Notes: Figures in parenthesis are standard errors. 1 farmer who was a non-user of Happy Seeder could not be contacted for obtaining the data on the yield of the wheat crop reducing the sample size further to 267. 3 farmers burnt the rice stubble prior to using Happy Seeder whereas 1 farmer could not be contacted for obtaining the data on the yield of the wheat crop reducing the sample size of Happy Seeder users to 88.

*** Significant at the 1% level

Table 11 : Descriptive Statistics and Mean Differences Between the Users and Non-Users of Happy Seeder

	Means, sample of farmers that used conventional tillage	Means, sample of farmers that used Happy Seeder	T-test, differences between means in column 1 and column 2
	(1)	(2)	(3)
Characteristics			
Age of the farmer	51.81 (0.87)	49.36 (1.34)	2.45 (1.70)
Number of years of Education of the farmer	8.16 (0.25)	9.95 (0.36)	-1.80*** (0.48)
Number of farmers that watched a television programme on farming	0.55 (0.03)	0.61 (0.05)	-0.06*** (0.06)
Number of farmers that were contacted by an extension agent in the year preceding the survey	0.24 (0.03)	0.64 (0.05)	-0.40*** (0.05)
Number of farmers that read agricultural magazines	0.19 (0.02)	0.47 (0.05)	-0.27*** (0.05)
Number of Farmers	267	88	

Notes: Figures in parenthesis are standard errors.
*** Significant at the 1% level

Table 10 shows the means of plot level characteristics between the users and non-users of Happy Seeder. The table also reports the test statistics for the difference in means across plots in the two samples (column 4, column 5 and column 6). The numbers in Table 10 indicate that the mean output of the wheat crop was similar across plots that were conventionally tilled and that were cultivated using Happy Seeder. This is a noteworthy feature of the estimates. It implies that the mean yield of the wheat crop was not significantly different across plots that were conventionally tilled by users of Happy Seeder and the conventionally tilled plots of the non-users of Happy Seeder. Thus, there is no reason to believe that the non-users of Happy Seeder would have obtained lower yields if they had used Happy Seeder. Moreover, though the users of Happy Seeder applied lower quantities of fertilizer and weedicide in comparison with the non-users of Happy seeder, their output of the wheat crop did not fall.

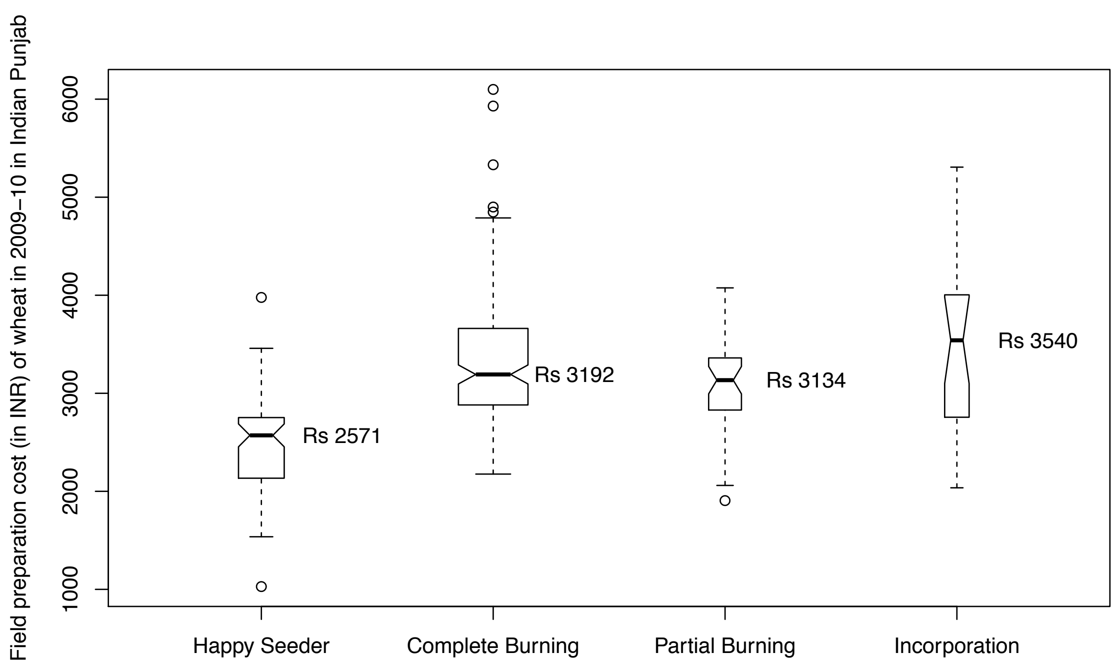
In Table 11 I report statistics on farmers' characteristics across the two samples. The users of Happy Seeder were more educated and may be more technically able (measured by indicators such as whether the farmer watched the television programme on farming and read agricultural magazines) than the non-users of Happy Seeder. They were also better connected with the agricultural extension network. This is not surprising as the agricultural adoption literature highlights that farmer's education and his connectivity with the extension network plays a crucial role in his decision to adopt a new technology (Rahm and Huffman, 1984) (Dorfman, 1996) (Nkamleu and Adesina, 2000).

I also performed the two-sample Welsch test to determine if the difference in mean yield per hectare of the three most popular varieties of wheat in Punjab is statistically significant across the two samples. I find that none of the three differences in means were statistically significant. However, this may be partly due to the small sample size in the Happy Seeder category.

Thereafter, I compare field preparation costs between the two samples in my study. I have already established that for the users of the Happy Seeder technology, Happy Seeder is less expensive to use than conventional tillage. Thus, I now compare the field preparation costs incurred by users of Happy Seeder with the field preparation costs of non-users of Happy Seeder. Figure 1 shows that Happy Seeder as a group has lower field preparation costs than conventional tillage. The median of the field preparation cost using Happy Seeder is less than the first quartile of the distribution of field preparation costs for plots that were fully burnt prior to sowing wheat. The notches surrounding the median determine the significance of differences between the values. Particularly, if the notches about two medians do not overlap in the graph, the medians are roughly significant at the 95% confidence level (McGill et al., 1978). This implies that the difference in the first box and the other boxes is significant. Users of Happy Seeder saved around Rs 600 (13$) in field preparation cost compared to non-users that burnt the residue and conventionally tilled their plots. Incorporation of residue is the most expensive alternative and hence it is not surprising that only 7.46% of the farmers in the sample incorporated the residue into the field.

Since the Happy Seeder technology is still in its infancy, the cost of hiring it varied considerably. The share of the cost of hiring Happy Seeder in the total cost ranged from 0% to 98%. I re-estimated field preparation costs using Happy Seeder assuming that Happy Seeder is available for hiring for Rs. 1000 ($21). This rate is the contract rate of a Roto-broadcaster in Punjab that has similar power requirements and working width as the Happy seeder (Singh et al., 2006). I assume that in the coming years the rental of Happy Seeder will stabilise to this rate. Happy Seeder continued to be a more viable option than complete burning of rice residue.

Figure 1: Variable Width Notched Box plots of field preparation costs across plots that were cultivated using Happy Seeder and Conventional Tillage



Notes: Each box plot has been made proportional to the square root of the number of plots in the corresponding group.

5 Conclusion

I find that the most important determinant of the decision to burn rice residue is usage of a combine harvester. The decision to use a combine harvester was in turn driven by the rice variety sown by a farmer. Coarse rice growers were significantly more likely to use a combine harvester than Basmati rice growers.

I conclude that rice residue is largely burnt as it is of limited value to the farmers both as livestock feed and non-feed use. Since, the machinery for planting wheat into loose rice residue was hitherto unavailable, the rice residue was burnt. The Happy Seeder technology overcomes this problem of planting wheat into the loose residue. My results imply that the Happy Seeder technology is a viable alternative to open field burning of rice residue in Punjab. Operators of this technology saved about Rs. 900- Rs. 1000 ($19-$21) on average in field preparation costs by using Happy Seeder compared to plots that were conventionally tilled. I also find that the Happy Seeder technology was a cheaper alternative to conventional tillage for non-users of this technology. Specifically, the median of the field preparation cost using Happy Seeder was Rs. 2571($55) whereas the median of field preparation costs for plots that were fully burnt prior to sowing wheat was Rs. 3192 ($68). The difference between the two medians of Rs. 621 ($13) was statistically significant. Increasing the availability of combine harvesters that have a spreader attached to them can further lower costs. This enables the farmers to evenly spread the loose residue. Yield of the wheat crop may also be negatively impacted if the loose residue is unevenly spread on the field (Singh et al., 2006). This latter feature merits that more such harvesters are developed.

This decrease in cost seems considerable enough to motivate farmers to switch to the Happy Seeder technology. Besides, Happy Seeder also entails substantial time savings for the farmers because it can be brought into the field immediately after the rice harvest enabling farmers to sow wheat while the rice straw is too green to burn. As stated earlier, these savings are significant to the farmers because any delay in planting wheat affects its productivity. Agricultural scientists further claim that farmers' reliance on weed control measures may decrease with usage of Happy Seeder as the mulch suppresses weeds (Singh et al., 2006). My study shows that operators of Happy Seeder had indeed applied lower quantities of fertilizer and weedicide to the wheat crop. Less usage of fertilizer and weedicide can have desirable external benefits.

Despite being a low-cost alternative to conventional tillage, farmers may not be inclined to adopt Happy Seeder because they may not believe that wheat will grow in fields covered with rice residue. Farmers that were aware of the Happy Seeder technology, but that were non adopters, were indeed skeptical. The reasons most cited for its failure were the high incidence of rats in fields covered with residue as well as an increased occurrence of weeds, both of which would harm the wheat crop. Although contact with extension agents did not come out to be signicant in my regressions, extension agents have a role to play in allaying these fears. This insignificance may be due to lack of variation in the sample to identify the effect of extension services. If these services were widespread then they might have impacted. Still farmers may be reluctant to switch practices. Hence, a spectrum of choices such as Balers, Happy Seeders need to be made available to the farmers along with a strict ban on burning rice residue.

Most importantly, I do not find that the Happy Seeder has a negative impact on profitability. Thus, the Happy Seeder technology has the potential to mitigate emissions from field burning of rice residue in other parts of the world. Hence from a social point of view the environmental benefits from widespread adoption of Happy Seeder are very large. Given that there are very limited alternatives to tackle emissions from the open field burning of rice residue, the adoption of the Happy Seeder technology needs to be accelerated. However, further research is required to assess its long-term impact on soil fertility and yield.

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