Rethinking Rice Cultivation: A Multiple Regression Analysis of Factors Influencing the Prevalence of Stubble Burning in Punjab

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Abstract: In recent years, stubble burning has become a major environmental problem. Although the government has taken steps to address this phenomenon, the rise in air pollution levels in northern India, especially Delhi, suggest that the issue is still not under control. In the period of 2016-19, Punjab recorded the maximum number of stubble burning events compared to other Indian states. This study investigated the impact of a variety of factors on the number of stubble burning instances in Punjab using multiple regression analysis. The results showed that the number of stubble burning instances of districts in Punjab is most strongly influenced by the area under rice cultivation, rural literacy rate, and the percentage of basmati rice cultivated in the total area under rice cultivation. Based on the results, we suggest that Punjab should promote crop diversification, impart technical, environmental and financial knowledge about the alternatives of burning of stubble, and promote a shift to Basmati varieties of paddy.

Keywords: stubble burning instances, Punjab, multiple regression, area under rice Cultivation, basmati rice, rural literacy rate, diversification

I. INTRODUCTION

Punjab plays a crucial role in Indian agriculture; despite occupying a small geographical area, it contributes significantly to the central rice procurement pool of India. In the 2018–2019 *kharif* (monsoon) season itself, Punjab was the largest contributor to the national pool, supplying 113.3 lakh metric tonnes (LMT) out of the total of 443.04 LMT ("Wheat, Paddy from Punjab, Haryana vital to India's food security", 2019).

Since the 1980s, a favorable minimum support price policy has made the rice-wheat system highly profitable in relation to other crops, which has led to a gradual shift from the maize-wheat cropping system to the water-intensive rice-wheat cropping system in Punjab. As a result of this pattern, the groundwater has depleted and the soil quality has deteriorated over time. To top it off, the mechanization of rice harvesting using the Combine Harvester in recent years to increase productivity has produced an abundance of crop residue on the field. Left with limited time to sow the seeds of the next crop, farmers typically burn their fields.

The increased burning of rice straw poses several problems. First, it poses a grave threat to the environment . Burning one tonne of straw releases 3 kg of particulate matter (PM), 60 kg CO, 1,460 kg CO_2, 199 kg ash, and 2 kg of SO_2 (Gupta et al., 2004). The release of PM in the atmosphere contributes significantly to global warming and climate change. Second, the crop residue burning, accounting for much of Delhi's pollution (Cusworth et al., 2018), has caused major health and respiratory problems. Residents of Delhi suffer from diseases related to air pollution at a rate that is 12 times higher than the national average (Kandlikar & Ramachandran, 2000).

On the agricultural front, stubble burning also has negative long-term ramifications for the farmers' own livelihood. The burning of crop residue results in persistent deterioration of the soil fertility, as the heat generated raises the temperature of the soil and depletes the bacterial and fungal population (Gupta et al., 2004). According to the National Policy for Management of Crop Residues (Government of India, 2014), one tonne of stubble burning generates a loss of all soil nutrients — 5.5 kilogram (kg) of nitrogen, 2.3 kg of phosphorus, 25 kg of potassium, and more than 1 kg sulphur of — except organic carbon.

The aforementioned discussion illuminates the significance of addressing the stubble burning phenomenon in order to put an end to this practice. This research study sought to contribute to the discourse by identifying the factors that influence stubble burning in Punjab and measure their relative impact. In the section below, selected factors in relation to stubble burning are examined using the multiple regression analysis: area under rice cultivation, rural literacy rate, percentage of small and marginal land holdings, and percentage of basmati rice cultivated in the total area under rice cultivation.

II. METHODOLOGY

Research Aim and Research Approach

In order to identify the most dominant factor(s) that influence stubble burning in Punjab, a multiple regression model was used, wherein the dependent variable, the number of the stubble burning instances (Y), was regressed against the following independent variables (X):

- **Area under Rice Cultivation**: As districts having a larger area under rice cultivation are likely to produce higher amounts of crop residue, it was hypothesized that this variable has a **high positive correlation** with the number of stubble burning instances.
- **Rural Literacy Rate:** Within the context of this research study, the literacy rate was used as a variable to represent the Punjabi farmers' awareness of the effects of stubble burning. Essentially, as low literacy rates undermine access to information, it was hypothesized that rural literacy rate has a **low negative correlation** with the dependent variable.
- **Percentage of Small and Marginal Land Holdings:** As marginal and small farmers owning less than 1 and up to 2 hectares of land would find it financially burdensome to purchase machines to remove the stubble or incorporate it into the soil, it was hypothesized that the percentage of small and marginal land holdings have a **high positive correlation** with the dependent variable.
- **Percentage of Basmati Rice Cultivated in the Total Area Under Rice Cultivation**: As the crop residue of the Basmati variety is as fodder for cattle, the farmer may not wish to burn it. Therefore, a **moderate negative correlation** between the percentage of basmati rice cultivated and the instances of stubble burning was hypothesized.

Data for the dependent and independent variables were gathered for the 22 districts of Punjab from diverse sources (see Table 1). The data was then normalized to bring all variables under the same range in order to produce accurate coefficients in the regression model (see Table 2 with variables, scaled from 0 to 100, for each district of Punjab).

Table 1

Selected Variables for Each District of Punjab

District	Number of Stubble Burning Instances (2016–2019)*	Area under Rice Cultivation ('000 Hectares)†	Rural Literacy Rate (%)‡	% Of Small and Marginal Land Holdings§	% of Basmati Rice¶
Gurdaspur	6,470	172.7	81.59	42.54	20.03
Pathankot	6	27.1	75.56	59.36	9.96
Amritsar	6,348	180.4	68	35.39	71.45
Tarn Taran	13,909	183.0	66.5	31.56	39.5
Kapurthala	6,869	115.0	75.9	33.13	5.74
Jalandhar	9,709	160.4	78.5	26.97	7.67
S.B.S Nagar	3,109	56.4	79	48.74	8.51
Hoshiarpur	1,912	65.8	83.7	50.45	15.35
Rupnagar	1,258	36.5	80.8	64.32	6.85
S.A.S Nagar	478	29.6	79	41.91	11.15
Ludhiana	19,640	259.3	78.8	34.05	6.517
Firozpur	38,231	187.5	65.06	20.11	18.29
Fazillka	2,811	105.0	65.21	24.06	62.57
Faridkot	13,477	117.7	64.6	23.74	11.97

Muktsar	22,004	142.3	61.8	21.63	44.27
Moga	14,061	181.5	68.2	24.03	3.8
Bathinda	26,286	130.3	62	30.92	4.98
Mansa	18,046	102.7	58.1	29.97	8.66
Sangrur	34,437	280.4	64.8	25.55	12.3
Barnala	15,374	113.5	64.7	32.65	1.23
Patiala	19,648	232.9	69	24.36	5.32
Fatehgarh Sahib	5,797	86.0	77.5	38.01	8.37

Sources of Data:

** 61st Bulletin Board of the Consortium for Research on Agroecosystem Monitoring and Modeling from Space (CREAMS) Laboratory (Indian Agricultural Research Institute, 2019). Although there have been instances where farmers in Punjab burn the residue of wheat, most of the instances involve burning of rice crop residue. Thus, the data collected is from 1st October to 30th November for every year from 2016-2019.*

† Basmati Crop Survey Report of Kharif 2019, Agricultural and Processed Food Products Export Development Authority (APEDA) (National Collateral Management Services Limited, 2019).

‡ Economical and Statistical Abstract of Punjab of 2019 (Sharma, et al., 2019). As agriculture is the primary source of livelihood in the rural areas of Punjab (Government of Punjab,, 2013) and the number of urban farmers is negligible, only the rural literacy rates of each district were taken for this study. A significant limitation with this approach is that a farmer might be illiterate but does not burn the crop residue and vice-versa.

§ Economical and Statistical Abstract of Punjab of 2019 (Sharma, et al., 2019).

¶ Basmati Crop Survey Report of Kharif 2019, Agricultural and Processed Food Products Export Development Authority (APEDA) (National Collateral Management Services Limited, 2019). Using this data, the percentage of the Basmati rice of the total area under rice cultivation was calculated.

Table 2

Scaled Variables (0-100) for Each District of Punjab

District	Number of Stubble Burning Instances	Area under Rice Cultivation ('000 Hectares)	Rural Literacy Rate (%)	% Of Small and Marginal Land Holdings	% of Basmati Rice
Gurdaspur	16.91039895	57.5	91.7578125	50.73888171	26.77299915
Pathankot	0	0.0	68.203125	88.7856915	12.43235545
Amritsar	16.5912361	60.5	38.671875	34.56333256	100
Tarn Taran	36.37148463	61.5	32.8125	25.89739124	54.50014241
Kapurthala	17.95421844	34.7	69.53125	29.44601402	6.422671604
Jalandhar	25.38391105	52.6	79.6875	15.52861767	9.171176303
S.B.S Nagar	8.117724003	11.6	81.640625	64.76598498	10.36741669
Hoshiarpur	4.986265533	15.3	100	68.62676351	20.10823127
Rupnagar	3.275343362	3.7	88.671875	100	8.00341783
S.A.S Nagar	1.234793983	1.0	81.640625	49.31382284	14.12702934
Ludhiana	51.36429039	91.7	80.859375	31.53451696	7.529193962
Firozpur	100	63.3	27.1875	0	24.29507263
Fazillka	7.338129496	30.8	27.7734375	8.925844913	87.35403019
Faridkot	35.24133421	35.8	25.390625	8.213315479	15.29478781

Muktsar	57.54872466	45.5	14.453125	3.440499268	61.29307889
Moga	36.76913015	61.0	39.453125	8.869294958	3.659925947
Bathinda	68.75081753	40.7	15.234375	24.46124858	5.340358872
Mansa	47.1942446	29.8	0	22.30556429	10.58103105
Sangrur	90.07455853	100.0	26.171875	12.31431822	15.76473939
Barnala	40.20405494	34.1	25.78125	28.36545748	0
Patiala	51.3852191	81.2	42.578125	9.618016363	5.82455141
Fatehgarh Sahib	15.14977109	23.3	75.78125	40.48071986	10.16804329

After the data were normalized, a multiple regression model was run. The dependent variable, the number of the stubble burning instances (Y), was modeled as the function of the independent variables (X) with corresponding coefficients, along with a constant term. Consequently, the multiple regression equation for the study took the following form:

$$\textit{Number of Stubble Burning Instances (Y)} = \beta_0 + \beta_1 AREA + \beta_2 LR + \beta_3 SMALL\_MARGINAL + \beta_4 BASMATI$$

Where,

β_0 = Intercept

β_1 = Area under Rice Cultivation (+ve)

β_2 = Rural Literacy Rate (-ve)

β_3 = Percentage of Small and Marginal Land Holdings (+ve)

β_4 = Percentage of Basmati Rice of the Total Area Under Rice Cultivation (-ve)

Note: Figures in Parentheses indicate the expected sign.

III. RESULTS AND DISCUSSION

Results

The results of the regression study are presented in Tables 3, 4 and 5. The R value is 0.883 and the coefficient of determination, R^2, is 0.7806. This means that 78.06% of variance of the number of stubble burning instances (Y) could be predicted on the basis of the independent variables (see Table 3).

Table 3

Multiple Regression Model Summary

Number of observations	**R**	**R square**	**Adjusted R square**	**Std. Error of Estimate**
22	0.883	0.7806	0.729	14.707

Moreover, the outcome of the F-test suggests that the regression model with the independent variables fits the data better than the intercept-only model: F(4, 17) = 15.12, MSE = 3270.88, p < .01 (see Table 4).

Table 4

ANOVA Table of Multiple Regression Model

	Df	**Sum Sq**	**Mean Sq**	**F value**	**p-value**

Regression	4	13083.5	3270.875	15.12	0.00001917
Residuals	17	3676.6	216.3		
Total	21	16760.1			

Of all the variables, only the percentage of small and marginal land holdings was found to have no predictive impact on the stubble burning instances: t(17) = 0.017 (lower than the critical value of 2.080), SEM = 0.207654, p=0.98683 (see Table 5).

Table 5

Coefficient Table of the Multiple Regression Model

Coefficients	**Estimate**	**Standard Error**	**t value**	**p-value**
(Intercept)	43.027433	11.759646	3.659	0.00194**
Area	0.567370	0.153945	3.686	0.00183**
RuralLiteracy	-0.510007	0.154350	-3.304	0.00419**
Small_marginal	0.003478	0.207654	0.017	0.98683
Basmati	-0.334245	0.121711	-2.746	0.01378*

Note: Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

The regression analysis was done again by eliminating this variable to determine and analyze the effect of other variables on the number of stubble burning instances. The increase in the adjusted R-squared value can be attributed to removal of the variable that was statistically insignificant

(see Table 6). Moreover, the increase in the F-value seems to indicate that this model is a better fit to predict the dependent variable: $F(3, 18) = 21.35$, $MSE = 4361.13$, $p < .01$ (see Table 7).

Table 6

Reduced Multiple Regression Model Summary

Number of observations	**R**	**R square**	**Adjusted R square**	**Std. Error of Estimate**
22	0.883	0.7806	0.7441	14.29

Table 7

ANOVA Table of the Reduced Multiple Regression Model

	Df	**Sum Sq**	**Mean Sq**	**F value**	**p-value**
Regression	3	13083.4	4361.13	21.35	0.000003714
Residuals	18	3676.6	204.26		
Total	21	16760			

Of all the independent variables, the area under rice cultivation exerted the strongest predictive impact on the instances of stubble burning: $b = 0.5658$, $t(18) = 4.825$, $p < 0.001$ (see Table 8).

Table 8

Coefficient Table of the Reduced Multiple Regression Model

Coefficients	Estimate	Standard Error	t value	p-value
(Intercept)	43.1224	10.0117	4.307	0.000424***
Area	0.5658	0.1172	4.825	0.000136***
RuralLiteracy	-0.5083	0.1125	-4.519	0.000266***
Basmati	-0.3343	0.1183	-2.826	0.011197*

Note: Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Discussion

This section will explore the underlying reasons for the particular influence of the statistically significant factors on the number of stubble instances in Punjab:

The most influential factor is the area under rice cultivation. Ever since the Green Revolution in India in 1965, which transformed Indian agriculture into an industrial system due to adoption of modern technology such as the use of tractors, irrigation facilities, fertilisers and pesticides, rice cultivation in Punjab has grown exponentially from 285 thousand hectares at the launch of the Green Revolution to 2894 thousand hectares in 2014–15 ("Why the Centre does not want Punjab to Diversify", 2017). The Green Revolution in India was initiated to increase food production and therefore, to make India self-sufficient in food grain. This policy has been instrumental in increasing the area under rice cultivation. Coupled with the growing use of combine harvesters and shortage of labour, it has resulted in an increase in the instances of stubble burning. While the *Agricultural Policy For Punjab* (Government of Punjab, 2013) strongly suggested reducing the total area for rice cultivation by at least 1.2 million hectares, this number has increased every year since then. The *Agricultural Statistics at a Glance 2018*, published by the Directorate of Economics and Statistics, showed that the area under rice cultivation increased from 2.9 million hectares in 2016–17 to 3.07 million hectares in 2017-18 (Government of India, 2019).

The second strongest factor that strongly influences the prevalence of stubble burning events is the rural literacy rate, $b = -0.5083$, $t(18) = -4.519$ $p < 0.001$. This finding is inconsistent with the original hypothesis: although the directionality was consistent, the coefficient was higher than expected. This seems to imply that limited access to information, frequently caused by low literacy rates translates into higher cases of stubble burning. Therefore, a vigorous programme to spread awareness about stubble burning can play a significant role in combating this issue.

Lastly, the percentage of Basmati rice cultivated in the total area under rice cultivation also has a moderate predictive impact on the number of stubble burning instances: $b = -0.3343$, $t(18) = -2.826$ $p = 0.011$. This is a critical finding. As the non-Basmati variety of paddy straw is high in silica content, it is usually not used as animal fodder, unlike the crop residue of the Basmati variety. Moreover, harvesting Basmati varieties leaves little residue. Therefore, increasing the planting of Basmati variety of rice can be pivotal in reducing the instances of stubble burning.

Finally, the multiple regression equation took the following form:

Number of Stubble Burning Instances (Y) = 43.1224 + 0.5658 (Area) - 0.5083 (RuralLiteracy) - 0.3343 (Basmati)

On a practical level, the regression analysis equation generated would allow the government to design policies to reduce stubble burning instances based on the area under rice cultivation, rural literacy rate and percentage of basmati of the total area under rice cultivation. Therefore, it is evident that if the administration of the Sangrur district decides to reduce its area under rice cultivation, then the stubble burning instances would potentially go down.

IV. POLICY RECOMMENDATIONS

Based on the results obtained from the regression analysis, in this section, policy recommendations that can help reduce the staggering instances of stubble burning in Punjab are presented:

1. **Promotion of crop diversification in Punjab to reduce area of rice cultivation**: Currently, the Punjab government's provision of high minimum support prices for rice and wheat have made it highly profitable for farmers to maintain rice-wheat systems, leading to substantial stubble burning. To reduce areas under rice cultivation, the

government should instead provide incentives for growing alternative crops such as maize, cotton, pulses, fruits and vegetables, such that the economic returns from growing these crops exceed those from growing rice and wheat.The government could also offer farmers up to 2-3 years of compensation if the growing of other alternative crops is not as profitable.

Crop diversification is a potentially lucrative proposition for farmers. According to the *Agricultural Policy For Punjab 2013* (Government of Punjab, 2013), the demand for food items like fruits and vegetables had been increasing at a higher rate than the demand for cereals with the trend likely to accelerate. Nonetheless, the success of crop diversification would depend on the improvement of the capabilities of farmers to adopt such high-value crops (Government of Punjab, 2013) and the government's investment in creating a market infrastructure to provide reliable procurement arrangements to ensure adequate demand for these crops.

2. **Switch to the Basmati Variety of Rice and Short-Duration Rice Varieties:** Under the minimum support price policy, the government in Punjab readily procures the non-Basmati varieties. As a result, farmers prefer the non-Basmati varieties to the Basmati ones as the former produces relatively more residue and cannot be used as animal fodder. As a comparison, Haryana that cultivates more Basmati varieties than the non-Basmati varieties during the same period has shown a greater reduction in the number of stubble burning cases than Punjab (Mahajan, 2019). Therefore, a **switch to the Basmati** variety in Punjab could prove to be viable to prevent stubble burning.

   Moreover, the government could push for planting Basmati rice by making the planting of the Basmati variety more profitable in relation to the growing of the non-Basmati varieties due to a huge export market in Europe, North America and West Asia. This could prove to be a win-win situation for both the farmers and the government.

   Short-duration rice varieties, viz. PR 126 and PR 127, developed by the Punjab Agricultural University, should also be considered by the farmers. These varieties have the added benefits of yielding more quintals per acre by consuming less water and taking less

time to mature after seeding (Krar, 2018). This would allow farmers to have more time to clear the stubble and prepare their fields for the planting of the subsequent crop.

3. **Provision of economic, technical, and educational support to promote alternatives to stubble burning:** One of the most actively promoted alternatives to stubble burning is the use of agricultural equipment to incorporate the paddy residue back into the soil. Since April 2018, the government has introduced a 50% subsidy on agricultural equipment, especially the Happy Seeder, for individual farmers, and a 80% subsidy for agricultural cooperatives and farmers' groups. To promote these practices, the government has been running awareness campaigns through short and long films, as well as establishing other rural channels of communication. One such example is the Custom Hiring Centres (CHCs) that provide the demonstration and training on the use of the Happy Seeder to the farmers.

   Despite the appreciable efforts taken by the government, there may be two potential reasons as to why the adoption of the Happy Seeder among farmers has been slow:

   A. **Lack of peer-to-peer learning:** First, the farmers may feel reluctant to use new technology, even when they are trained on how to use the machines at the CHCs because they may feel concerned about the machines' impact on their farms' yield. In order to overcome their reluctance, the government should identify *farmer representatives in each village* who could lead the way for other farmers to adopt Happy Seeders. This peer-to-peer learning could prove to be a more persuasive way to drive change and reduce cases of stubble burning in a given village.

      With such an approach, the government would be addressing both the behavioral and the technical challenges that deter farmers from using Happy Seeders and other agricultural equipment to manage the crop residue in-situ. Just as herd behavior plays a significant role in forcing a farmer to burn the crop residue (Lopes, Viriyavipart, & Tasneem, 2019), peer-to-peer learning could lead to their adoption of Happy Seeder machines.

B. **Lack of awareness of affordability of Happy Seeder:** Second, farmers may not consider it to be financially viable for them to purchase the Happy Seeder and the other agricultural equipment. In fact, as this study did not find a significant relationship between the percentage of small and marginal landholdings and the number of stubble burning incidents, it seems that farmers would opt for the easier and cheaper method of stubble burning regardless of the amount of land the farmer owned.

   Evidently, the farmers are unaware of the fact that the usage of Super Straw Management System (SMS) and Happy Seeder is the best option for a farmer to increase profits by generating higher yields and reducing labour, fuel and machinery costs. A study published in *Science* showed that farmers could increase their profits if they abandon the practice of stubble burning and adopt no-till practices to grow wheat (Shyamsundar et al., 2019).

   Therefore, to help farmers know about these benefits, the government should coordinate with nongovernmental organisations and agricultural universities to formulate comprehensive campaigns that combine technical and economic training. Essentially, farmers should not acquire technical knowledge, but also evidence-based information to enable them to make wise economic decisions (Bhuvaneshwari, Hettiarachchi, & Meegoda, 2019).

Apart from the Happy Seeders, the government should also extensively promote machines such as balers for the ex-situ management of rice straw to help farmers who grow vegetable crops after the cultivation of paddy. With the help of the machines, farmers could clear the stubble and use it to feed cattle, produce compost, biomass, biochar and/or fertilizers. They could even generate additional income from selling the straw to industries who make products out of crop residue. The development of industries which use the crop residue as a raw material and efficient collection mechanisms would create demand for the crop residue and convince more farmers to sell their stubble.

V. CONCLUSION

The phenomenon of stubble burning has, unfortunately, become a widespread practice in northern India, especially Punjab. It has led to rising emissions of greenhouse gases (Gupta et al., 2004) and a concomitant increase in respiratory health problems (Cusworth et al., 2018) and the deterioration in the quality of the soil (Gupta et al., 2004). The persistence of stubble burning in Punjab highlights the need for concrete steps to tackle this issue.

This study has identified various factors that affect the number of stubble burning instances in Punjab. After running the regression model with all the variables, the area under paddy cultivation, rural literacy rate, and percentage of Basmati rice cultivated in the total area under rice cultivation were identified as statistically significant factors that influence stubble burning in Punjab. Specifically, the area under paddy cultivation is positively correlated with the number of stubble burning instances, while the rural literacy rate and percentage of Basmati rice of the total area under rice cultivation share a negative correlation.

Based on the results, this study has also proposed recommendations for policymakers to help Punjab address the stubble burning phenomenon. The recommendations comprise crop diversification with a shift away from the rice-wheat systems, incentives for growing Basmati varieties of paddy and short-duration rice varieties, along with comprehensive economic, technical, and education support to awareness programmes to impart technical, economic and environmental knowledge about the in-situ and ex-situ uses of stubble. This study could thus offer policymakers the insights and impetus to tackle the serious problem of stubble burning.

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