Tables and figures

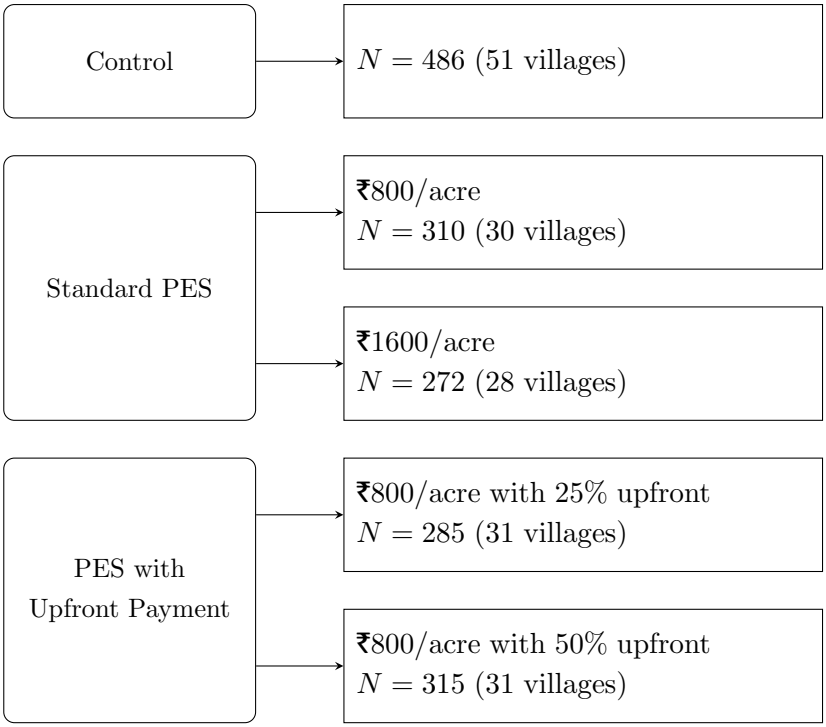


Figure A1. : Experimental Design

Note: Treatments are assigned at the village level. See text for additional detail.

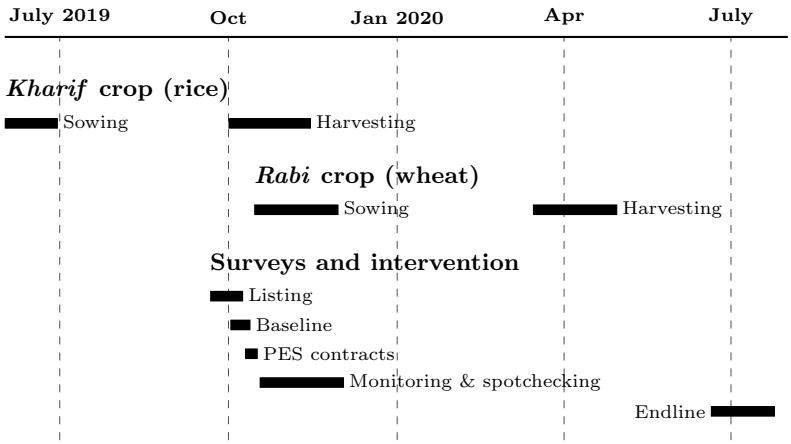
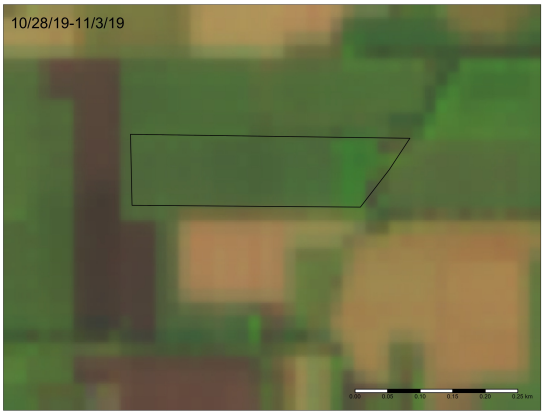
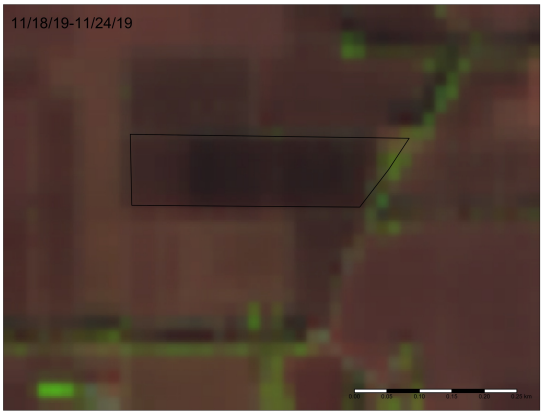


Figure A2. : Timeline

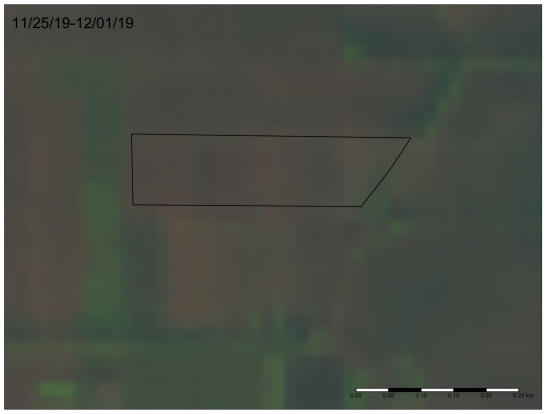
Note: Calendar of agricultural activities and timeline of data collection and implementation.



Around harvest time



Just after burning



One week after burning

Figure A3. : Visual Signs of Burning in Imagery: Example

Note: Imagery from Sentinel-2 showing a study plot at different points in the agricultural season.

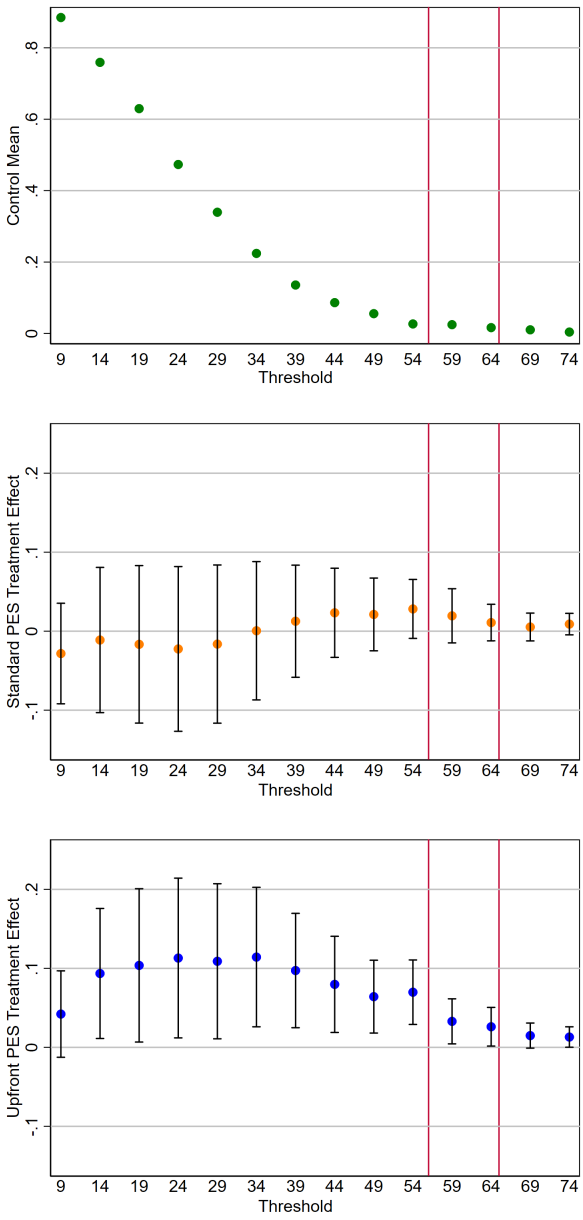


Figure A4. : Robustness of Treatment Effects on Not Burning

Note: The graphs show the control mean and treatment effects estimated using equation (1) on binary remote sensing measures of burning outcomes (unburned) based on different classification thresholds. The classification thresholds are indicated on the x-axis. The binary remote sensing measures take value 1 if the farmer did not burn any of his plots. The top panel shows the mean in the control group. The middle panel shows the treatment effects of the standard PES treatment arm. The bottom panel shows the treatment effect of the upfront PES treatment arm. The two red lines in the middle and bottom graph indicate the thresholds that maximize overall model accuracy (threshold at 65), and that classifies burning to balance type I and type II errors (threshold at 56).

Table A1—: Comparison of Study Sample, Cooperative Listing, and Census Sample

	Census	Cooperative members	Study eligible	Study enrolled	Diff Coop. - Census	Diff Coop. - Study
	(1)	(2)	(3)	(4)	(5)	(6)
Age (years)	46.79	46.99	46.53	48.34	0.20	1.35
	(14.31)	(14.31)	(14.53)	(12.82)	[1.02]	[2.22]
Total experience in agriculture (years)	25.66	26.29	25.05	28.92	0.63	2.63
	(14.58)	(14.72)	(14.25)	(13.39)	[1.04]	[2.31]
Total area of paddy land in acres (reported)	7.71	7.99	5.54	5.26	0.28	-2.73
	(8.03)	(7.69)	(2.93)	(2.47)	[0.56]	[0.58]
1(Knowledge of CRM techniques)	0.87	0.89	0.86	0.79	0.02	-0.10
	(0.33)	(0.32)	(0.35)	(0.41)	[0.02]	[0.07]
1(Tried a CRM technique other than burning)	0.90	0.90	0.85	0.74	-0.00	-0.16
	(0.30)	(0.31)	(0.36)	(0.45)	[0.02]	[0.07]
Distrust index excluding distrust in family (continuous)	-0.01	-0.32	-0.03	0.80	-0.31	1.12
	(3.49)	(3.43)	(3.57)	(3.92)	[0.25]	[0.67]
1(Aware of government PES program)	0.37	0.36	0.38	0.31	-0.01	-0.06
	(0.48)	(0.48)	(0.49)	(0.47)	[0.03]	[0.10]
1(Applied to government PES program 2019)	0.19	0.18	0.16	0.19	-0.01	0.01
	(0.40)	(0.39)	(0.37)	(0.40)	[0.03]	[0.08]
N	479	339	190	38		

Note: Standard deviations reported in parentheses and standard errors reported in brackets. Column 1 includes the sample of respondents in the census survey; column 2 includes the subgroup of participants in the census survey who are part of the local farmers' cooperative society; column 3 restricts the census sample to those respondents who would have been eligible for the baseline survey; column 4 includes the sample of census respondents in the study. Columns 1 to 4 are the means in the samples, and columns 5 and 6 are the differences between the means.

Table A2—: Summary Statistics and Balance

	N	Control		Treatment vs Control	Standard vs Control	Upfront vs Control	Upfront vs Standard
		Mean	SD				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A: Demographics							
Age (years)	1668	48.675	12.732	-0.158	-0.448	0.124	0.610
				(0.751)	(0.816)	(0.825)	(0.653)
Total experience in agriculture (years)	1668	28.055	13.144	-0.184	-0.452	0.078	0.522
				(0.788)	(0.860)	(0.874)	(0.732)
Highest educational class passed	1658	7.213	4.197	-0.147	-0.200	-0.096	0.114
				(0.228)	(0.265)	(0.270)	(0.283)
1(Ever signed a written contract)	1440	0.483	0.500	-0.048	-0.049	-0.048	0.001
				(0.039)	(0.044)	(0.044)	(0.041)
Panel B: Income							
Total income	1602	125.694	172.588	-4.655	1.060	-10.190	-10.352
				(11.386)	(12.886)	(13.798)	(14.493)
Non-agricultural income	1455	18.076	66.407	-1.393	-2.545	-0.277	3.150
				(4.563)	(5.136)	(6.630)	(8.084)
Total agricultural profit	1521	114.177	155.748	-2.759	4.674	-9.905	-14.483
				(11.246)	(12.700)	(12.865)	(12.426)
Total area of land in acres (measured)	1668	4.986	2.816	0.327	0.350	0.304	-0.049
				(0.173)	(0.203)	(0.188)	(0.181)
Paddy production in 1000kg	1513	13.250	9.593	0.684	1.069	0.308	-0.768
				(0.625)	(0.736)	(0.700)	(0.722)
Panel C: Heterogeneity variables							
Liquidity constraints index	1668	0.488	0.500	0.016	0.027	0.005	-0.016
				(0.040)	(0.044)	(0.046)	(0.043)
Distrust index	1655	0.476	0.500	0.043	0.058	0.029	-0.032
				(0.035)	(0.039)	(0.040)	(0.034)
CRM information constraints index	1676	0.444	0.497	0.026	0.062	-0.009	-0.076
				(0.034)	(0.040)	(0.039)	(0.041)
CRM access constraints index	1651	0.445	0.497	0.076	0.078	0.073	-0.009
				(0.033)	(0.036)	(0.038)	(0.034)
CRM negative beliefs index	1676	0.500	0.501	0.069	0.095	0.043	-0.060
				(0.035)	(0.039)	(0.038)	(0.032)
Panel D: Burning							
1(Burned paddy residue in 2018)	1576	0.684	0.465	0.025	0.044	0.006	-0.037
				(0.034)	(0.037)	(0.039)	(0.035)
P-value of joint F-test				0.487	0.492	0.683	0.805

Note: Column 1 shows the number of non-missing observations in the baseline survey out of a total of 1,668 observations; 486 observations for the control group and 1,182 observations for the treatment groups. Columns 2 and 3 show the summary statistics for the control group in the baseline. Column 4 shows the coefficient from regressing the baseline variable on an indicator for any treatment. Columns 5 and 6 are the coefficients from regressing the baseline variable on separate indicators for the standard and upfront PES treatments. Column 7 shows the coefficient from regressing the baseline variable on an indicator for the upfront PES treatment, omitting the control group (coefficients are relative to standard PES). Income variables cover past 12 months and are measured in ₹1,000. Heterogeneity variables in Panel C are binary. Coefficients are estimated using equation (1), which includes strata fixed effects and clusters standard errors at the village level.

Table A3—: Attrition from the Endline Survey

	Attrition (1)
Standard PES	0.051
	(0.025)
Upfront PES	0.044
	(0.025)
p-val: Standard PES = Upfront PES	0.786
Control mean	0.130
Standard PES mean	0.187
Upfront PES mean	0.182
N	1668

Note: "Attrition" equals 1 if the respondent was not in the endline. Coefficients are estimated using equation (1), which includes strata fixed effects and clusters standard errors at the village level.

Table A4—: Heterogeneity of Attrition from the Endline Survey

Outcome variable:	Attrition																
Heterogeneity variable:	Age	Agric. Exp.	Educ.	Ever Signed Contract	Income	Non-Agric. Income	Agric. Revenue	Land Area	Paddy Prod.	Liquidity Const.	Distrust	Info. Const.	Access Const.	Neg. Beliefs	Burned Paddy Residue in 2018	Unburned (Balanced)	Unburned (Maximum)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
Standard	-0.043	0.001	0.079	0.059	0.050	0.071	0.052	0.110	0.093	0.052	0.036	0.053	0.057	0.040	0.034	0.058	0.061
	(0.094)	(0.056)	(0.049)	(0.035)	(0.029)	(0.024)	(0.027)	(0.046)	(0.039)	(0.032)	(0.029)	(0.029)	(0.033)	(0.036)	(0.046)	(0.027)	(0.025)
Upfront	-0.029	0.035	0.043	0.045	0.049	0.050	0.041	0.074	0.041	0.045	0.071	0.046	0.045	0.042	0.030	0.035	0.040
	(0.096)	(0.054)	(0.045)	(0.033)	(0.030)	(0.027)	(0.027)	(0.049)	(0.041)	(0.034)	(0.031)	(0.027)	(0.033)	(0.036)	(0.040)	(0.028)	(0.026)
Het. Var.	-0.001	-0.001	0.001	0.016	0.002	0.006	0.000	0.007	0.001	0.033	0.031	0.040	0.013	-0.005	-0.014	-0.011	0.054
	(0.001)	(0.001)	(0.004)	(0.030)	(0.001)	(0.003)	(0.001)	(0.006)	(0.002)	(0.029)	(0.026)	(0.026)	(0.032)	(0.031)	(0.037)	(0.038)	(0.059)
Standard x Het. Var.	0.002	0.002	-0.004	0.003	-0.000	-0.008	-0.000	-0.012	-0.003	-0.002	0.028	-0.008	-0.013	0.020	0.040	-0.035	-0.102
	(0.002)	(0.002)	(0.006)	(0.048)	(0.001)	(0.003)	(0.001)	(0.008)	(0.002)	(0.045)	(0.041)	(0.040)	(0.046)	(0.050)	(0.056)	(0.052)	(0.075)
Upfront x Het. Var.	0.001	0.000	0.000	0.016	-0.002	-0.007	-0.000	-0.006	-0.000	-0.002	-0.053	-0.004	0.000	0.004	0.029	0.036	0.007
	(0.002)	(0.002)	(0.005)	(0.048)	(0.001)	(0.003)	(0.001)	(0.008)	(0.002)	(0.045)	(0.038)	(0.043)	(0.044)	(0.045)	(0.049)	(0.052)	(0.080)
p-val: Standard x Het. Var. = Upfront x Het. Var.	0.801	0.401	0.455	0.815	0.305	0.724	0.132	0.473	0.138	0.998	0.050	0.933	0.760	0.751	0.838	0.147	0.125
p-val: Standard x Het. Var. = 0	0.315	0.332	0.456	0.944	0.832	0.029	0.853	0.139	0.168	0.964	0.495	0.843	0.777	0.690	0.472	0.503	0.178
p-val: Upfront x Het. Var. = 0	0.433	0.845	0.975	0.742	0.265	0.026	0.836	0.470	0.969	0.966	0.166	0.925	0.996	0.928	0.553	0.493	0.933
Control mean	0.130	0.130	0.130	0.127	0.134	0.128	0.131	0.130	0.128	0.130	0.128	0.130	0.128	0.130	0.122	0.130	0.130
Standard PES mean	0.187	0.187	0.186	0.193	0.187	0.191	0.188	0.187	0.183	0.187	0.188	0.187	0.186	0.187	0.190	0.188	0.188
Upfront PES mean	0.182	0.182	0.182	0.184	0.171	0.173	0.179	0.182	0.174	0.182	0.181	0.182	0.183	0.182	0.178	0.183	0.183
N	1668	1668	1658	1440	1602	1455	1603	1668	1513	1668	1655	1668	1651	1668	1576	1664	1664

Note: "Attrition" equals 1 if the respondent was not in the endline. Het. Var. is the heterogeneity variable, shown in the column title. "Agric. Exp." refers to the total experience in agriculture (years). "Educ." refers to the highest educational class passed. "Ever Signed Contract" is a dummy taking value 1 if the farmer ever signed a written contract before and 0 otherwise. "Income" refers to the total income in ₹'s in the past 12 months. "Non-Agric. Income" refers to non-agricultural income in ₹in the past 12 months. "Agric. Revenue" refers to the total revenue from agriculture in 1000 ₹. "Land Area" refers to the total area of land in acres. "Paddy Prod." refers to the paddy production in 1000kg. "Financial Const." refers to a financial constraints index. "Distrust" refers to an index indicating the farmer's distrust in categories of people and organizations. "Info. Const." refers to a CRM information constraints index. "Access Const." refers to a CRM access constraints index. "Neg. Beliefs" refers to a CRM negative beliefs index. "Burned Paddy Residue in 2018" equals 1 if the farmer reported having burned paddy residue in 2018 and 0 otherwise. "Unburned (Balanced)" refers to the remote sensing measure of not-burning using the balanced accuracy threshold, and "Unburned (Maximum)" refers to the remote sensing measure of not-burning using the maximum accuracy threshold. The number of observations (N) reflects non-missing observations of the heterogeneity variable. Coefficients are estimated using a modified version of equation (1), which includes both a level and treatment interactions for the heterogeneity variable, includes strata fixed effects and clusters standard errors at the village level.

Table A5—: Treatment Effects on Measures of Not Burning

	Unburned (Max Accuracy) at plot-level (1)	Spot Check (2)
Standard PES	-0.004	0.013
	(0.040)	(0.076)
Upfront PES	0.036	0.103
	(0.043)	(0.073)
p-val: Standard PES = Upfront PES	0.280	0.234
Control mean	0.130	0.373
Standard PES mean	0.111	0.364
Upfront PES mean	0.180	0.456
N	743	714

Note: "Unburned (Max Accuracy) at Plot-Level" equals 1 if a plot was not burned according to a remote sensing measure that classifies burning to maximize overall model accuracy. "Spot Check" equals 1 if a plot showed no sign of burning during a random spot check. Plot level regressions are weighted by the inverse of the number of plots the farmer has. Treatment effects are estimated using equation (1), which includes strata fixed effects and clusters standard errors at the village level.

Table A6—: Treatment Effects Disaggregated by Subtreatment

	Contract Take-Up (1)	Complied with Contract (2)	Unburned (Max Accuracy) (3)
800/acre	0.743	0.068	0.007
	(0.030)	(0.016)	(0.033)
1600/acre	0.707	0.104	0.036
	(0.036)	(0.025)	(0.038)
800/acre with 25% Upfront	0.737	0.177	0.056
	(0.030)	(0.029)	(0.032)
800/acre with 50% Upfront	0.702	0.189	0.094
	(0.029)	(0.029)	(0.046)
p-val: 800/acre = 1600/acre	0.441	0.219	0.461
p-val: 800/acre = 800/acre with 25% Upfront	0.885	0.001	0.170
p-val: 800/acre = 800/acre with 50% Upfront	0.310	0.000	0.059
p-val: 1600/acre = 800/acre with 25% Upfront	0.510	0.051	0.617
Control mean	0.000	0.000	0.091
N	1668	1668	1664

Note: "Complied with Contract" equals 1 if the respondent called to request monitoring of his plots, and monitoring led to the conclusion that the respondent complied with the contract i.e. did not burn his paddy residue. "Unburned" equals 1 if the farmer did not burn any of his plots. "800/acre" is the Standard PES arm that received ₹800 per acre conditional on not burning. "1600/acre" is the Standard PES arm that received ₹1600 per acre conditional on not burning. "800/acre with 25% Upfront" is the upfront PES arm that received 25% of ₹800 per acre unconditionally upfront and 75% conditional on not burning. "800/acre with 50% Upfront" is the upfront PES arm that received 50% of ₹800 per acre unconditionally upfront and 50% conditional on not burning. Treatment effects are estimated using a modified version of equation (1), which includes indicators for each subtreatment, includes strata fixed effects and clusters standard errors at the village level.

Table A7—: Crop Residue Management Methods: Lee Bounds

	CRM techniques	
	Baler	Seeder
Standard PES		
Lower bound	-0.025	-0.028
	(0.027)	(0.021)
Upper bound	0.036	0.047
	(0.025)	(0.017)
Upfront PES		
Lower bound	0.088	0.006
	(0.030)	(0.022)
Upper bound	0.145	0.068
	(0.028)	(0.019)

Note: "Baler" equals 1 if the farmer reported in the endline that he used a baler in the 2019 Kharif season. "Seeder" equals 1 if the farmer reported in the endline that he used a Happy Seeder or a Super Happy Seeder in the 2019 Kharif season. Lee bounds correspond to the treatment effect estimates reported in Table 1. To construct bounds, we trim observations from the control group within strata and include strata fixed effects in the estimation because our randomization is stratified.

Table A8—: Effects on Agricultural Yield and Sowing Delays

	Paddy Yield (1)	Wheat Yield (2)	Days (3)
Standard PES	-0.026	-0.013	-0.217
	(0.039)	(0.015)	(0.643)
Upfront PES	-0.066	0.008	-0.120
	(0.045)	(0.015)	(0.627)
p-val: Standard PES = Upfront PES	0.356	0.151	0.881
Control mean	1.249	0.745	18.364
Standard PES mean	1.237	0.736	17.943
Upfront PES mean	1.194	0.756	18.380
N	1367	1378	1386
Lee Bounds			
Standard PES			
Lower bound	-0.103	-0.035	-1.032
	(0.037)	(0.013)	(0.552)
Upper bound	0.037	0.008	0.320
	(0.037)	(0.015)	(0.524)
Upfront payment PES			
Lower bound	-0.113	-0.013	-0.937
	(0.037)	(0.010)	(0.532)
Upper bound	0.005	0.027	0.425
	(0.037)	(0.012)	(0.505)

Note: "Paddy Yield" is the amount of paddy produced in Kharif 2019 (log of 1000 kg per acre). "Wheat Yield" is the amount of wheat produced in Rabi 2020 (log of 1000 kg per acre). "Days" is the number of days after the paddy harvest that passed before the farmer started sowing the Rabi crop. The bottom panel shows the Lee bounds for the treatment effects. To construct bounds, we trim observations from the control group within strata and include strata fixed effects in the estimation because our randomization is stratified.

Table A9—: Heterogeneity of Treatment Effects on Contract Take-Up

Outcome variable:	Program Take-Up	
Type of constraint:	Liquidity Constraints	Distrust
	(1)	(2)
Upfront PES	0.004	-0.018
	(0.040)	(0.041)
Highly constrained	0.020	0.024
	(0.036)	(0.042)
Upfront PES × Highly constrained	-0.015	0.035
	(0.051)	(0.059)
Pooled PES mean	0.734	0.735
N	1182	1172

Note: The row labeled "Type of constraint" indicates the heterogeneity variable: "Liquidity Constraints" is an index indicating liquidity constraints, including constrained access to cash and loans. "Distrust Constraints" is an index indicating the farmer's distrust in categories of people and organizations. All indices are binary and take value 1 if the farmer's constraint is larger than or equal to the median. The outcome variable is indicated in the top row of the table: "Program Take-Up" equals 1 if the respondent signed a contract to participate in the PES program. Treatment effects are estimated using a modified version of equation (1), which omits the control group and includes both a level and an interaction term (with upfront PES) for the heterogeneity variable, includes strata fixed effects and clusters standard errors at the village level.

Table A10—: Heterogeneity of Pooled Treatment Effects on Contract Compliance by CRM Equipment Constraints

Outcome variable:	Complied with Contract		
Type of constraint:	Information Constraints	Access Constraints	Negative Beliefs about Burning Alternatives
	(1)	(2)	(3)
Highly constrained	-0.063	-0.004	-0.040
	(0.019)	(0.024)	(0.020)
Pooled PES mean	0.135	0.136	0.135
N	1182	1168	1182

Note: The row labeled "Type of constraint" indicates the heterogeneity variable: "Information Constraints" is an index indicating the farmer's lack of knowledge about CRM equipment. "Access Constraints" is an index indicating the farmer's difficulties in accessing CRM equipment. "Negative Beliefs about Burning Alternatives" is an index indicating the strength of the farmer's negative beliefs about the impact of CRM equipment on soil health and yield as compared to burning. All indices are binary and take value 1 if the farmer's constraints are larger than or equal to the median. The outcome variable is indicated in the top row: "Complied with Contract" equals 1 if the respondent called to request monitoring of his plots, and the monitoring determination was that the respondent complied with the contract, i.e., did not burn his crop residue. Treatment effects are estimated using a modified version of equation (1), which omits the control group and includes both a level and an interaction term (with upfront PES) for the heterogeneity variable, includes strata fixed effects and clusters standard errors at the village level.

Intervention script

Program description

Our organization is working on agricultural and environmental issues and we want to help farmers manage paddy stubble after the paddy harvest this season. I am here to share details of a program that we are introducing to some farmers in this village during the paddy crop season in the month of October and November 2019.

To encourage farmers to manage paddy stubble in an environmentally-friendly manner, we will offer you an agreement that will pay you if you do not burn your paddy field(s) this season. We will compensate you at a rate of [treatment rate] per acre (up to a max. of [treat rate x 100]). You may use any alternate methods of managing the residue. Other than burning the stubble, we do not place any condition on what this method should be.

This monetary compensation will only be given to you if a monitor, during the months of October and November, assesses that that your paddy field has not been burned. If you are interested in participating, I will explain the terms and conditions of the agreement to you that will help you decide whether you want to enroll in the programme or not. If you are uncertain about signing the agreement because you are unsure whether you would be fulfilling the conditions of the contract, let me remind you that there is no harm in participating in the programme. If you burn, you will not be penalized in any way by us. If you do not burn, you will be given the reward. By signing you are only giving yourself a chance to win money.

If you would like someone in the house to help you make a decision and listen to the details of the programme, please feel free to invite them now. Please remember that whoever signs the agreement must have a bank account to enable payments at a later date.

Information handout

This document provides details on some of the items in the agreement and is to help the enrollee farmer with complying with the terms and conditions of the agreement.

Monitoring visits

1) The enrollee farmer is expected to initiate monitoring for all plots, with a maximum of two requests to J-PAL. All plots must be covered through these two requests.

2) Each request will result in up to two visits by J-PAL monitors. The second visit will only be performed if J-PAL determines that it is necessary to assess burning.

3) In addition to the requested and scheduled visits, J-PAL can also make unannounced visits to the plots for checks.

When to call for monitoring: The enrollee farmer should call once all the pre-sowing work related to stubble has been completed on the plots covered under the request. This means all activities related to stubble like removing or processing of stubble must have been completed and no further managing of stubble is required before sowing. In general,

requests should be made at least four days before sowing. The request can occur if any of the following applies:

1) After the straw and stubble have been completely removed from the plot but no later than 4 days before sowing.

2) After the straw has been rolled into bales/bundles but no later than four days before sowing.

3) After the straw/stubble has been mixed or blended into the soil but no later than four days before sowing.

4) If using the Happy seeder or mulcher: once sowing preparation is complete but no later than four days before sowing. In these cases, a second monitoring visit will be made post sowing.

Remember, up to two requests can be initiated. If some plots are ready, call to schedule the first monitoring, keeping in mind that any plots not covered under the first request have to be monitored as part of the second request. If all plots are ready for monitoring, they can be inspected in a single visit.

Phone numbers for calling: xxx, xxx, xxx

What counts as burning? The agreement requires that farmers do not burn any of their plots. This will be broken if any of the following (or any other form of burning) are detected by the monitor. The farmer will not be eligible for payment if any of the following is detected during monitoring.

- Burning of the upper layer of loose straw left behind by the harvester.
- Burning of the standing stubble.
- Burning of straw collected in one part of the plot.
- Burning as mentioned above on any of the plots.

Important

1) J-PAL SA is not related to any government in any manner. The failure of the enrollee farmer to meet any term or condition in the agreement will not attract any penalty or fine, and no legal action will be taken. This is clearly stated in the agreement. We are only trying to find if this a good way to help the farmers with resolving the residue issue. We cannot impose any fines or penalties since we are not related to government.

2) The only consequence of not fulfilling any of the term or condition in the agreement will be that farmer will become ineligible for payment of amount as mentioned in the agreement.

3) In case the farmer does not request monitoring as specified above, J-PAL will not be liable to pay any amount as mentioned in the agreement. Decision on payment to be made will only be taken once all the plots have been fully monitored.

4) If after the first monitoring visit and after analyzing the observations recorded, the J-PAL SA team ascertains that burning happened in even one of the plots, no further monitoring visit will be conducted. In this case, the farmer will be ineligible to receive the payment.

5) At the time of the monitoring visit, we may also request you for bank account details. The bank account transfer is the fastest and easiest way to transfer the amount. After the monitoring has been completed for all the plots and it is assessed that burning has not happened on any plots, the payment will be made directly into the account.

6) The enrollee farmer should keep the agreement and information handout safe for use later. The ID and phone numbers given on them are to be used for calling.

SAMPLE CONTRACT

Standard PES: ₹800 per acre with no upfront payments

${village_id}

${a_hhid}

${resp_id}

Contract for Incentive Program Offering Payment for No-Burning on Paddy Plots

This Agreement is executed on _____[Insert date]

by and between ${resp_name},

residing at

_____[Insert Enrollee Address]

AND

Abdul Latif Jameel Poverty Action Lab South Asia at the Institute for Financial Management and Research, which is registered under Society Registration Act 1860 (hereinafter referred to as "J-PAL SA"), located at Buhari Towers, 2nd Floor, 4, Moors Road, Chennai 600006

Background

J-PAL SA proposes to partner with [${resp_name}] (hereinafter referred to as "Enrollee") with the following summary of responsibilities.

Based on the field measurement completed in a previous visit, (s)he cultivates _#ACRE____ acres of paddy currently.

Summary of responsibilities

J-PAL SA

1. Visit Enrollee's paddy plots, which were mapped during the survey visit to the Enrollee that was already conducted, to assess whether burning occurred. This monitoring visit will take place once Enrollee informs J-PAL SA by phone, as described below. J-PAL will visit the plots to assess whether they have been burned within **3** days of being called by the Enrollee. 'Monitoring will be available only beginning on 15 October 2019 or today (whichever date is later). Enrollees that call to be monitored before this date cannot be monitored by J-PAL South Asia and therefore are not eligible for payment.
2. The J-PAL SA team will determine if the field has been burned based on the observations made by the monitor during their visit. The process of inspection is summarized below:
    a) The J-PAL SA monitor will visit all the paddy plots as measured during a previous visit.
    b) The monitor will physically inspect each plot for visual cues and record the observations. Based on the recorded observations during the visit, the J-PAL SA team will determine whether the field was burned or not.
3. If the paddy plots do not appear to be burned, as assessed by the J-PAL SA team, then J-PAL SA will provide Enrollee with an amount such that the total payment amount for not burning is Rs **800** per acre of enrolled land. The maximum overall payment is Rs **8000**. The payment amount for the Enrollee is Rs ${pes_amount}.

Enrollee

1. Enrollee confirms, by signing this agreement, that the paddy plots mapped during the survey visit represent all of his/her paddy plots. All paddy plots cultivated in the 2019 Kharif season must be enrolled.
2. After harvesting paddy and managing and processing stubble, and at least 4 days before sowing wheat or any other rabi crop, Enrollee is required to call J-PAL SA at the numbers provided on the information handout between the hours of 9:00 am and 5:00 pm, on any date between 15 October and 30 November 2019 to indicate that the fields are ready to be monitored. We will not be able to monitor before the above mentioned date and farmers requesting for monitoring to be conducted before the 15th October will not be eligible.
3. The Enrollee may request up to two monitoring visits to cover all paddy plots, for example, for some plots that are ready for monitoring early and others that are ready late. Each plot will be monitored up to two times.
4. The Enrollee will also allow additional, unscheduled monitoring to occur at any point in time.

5. If it is assessed by the J-PAL SA team that the field is not burnt, the Enrollee will receive a payment amount as indicated above. For the enrollee to be eligible for payment, no burning should have taken place on any of the plots.
6. The assessment of whether a field is burnt or not is not dependent on whether the field was burnt deliberately or accidentally, or by the Enrollee or someone else.

Payment and contract

1. J-PAL SA shall not be obligated to pay the Enrollee any amount in excess of what is mentioned above.
2. By signing this agreement, the Enrollee acknowledges that J-PAL SA reserves the right to rescind the payment of the aforementioned amount if the Enrollee fails to fulfil any of the responsibilities designated to him/her under "Summary of Responsibilities" and/or breach of the terms of this agreement in any manner or extent.
3. There will be no legal implications for the Enrollee for the breach of the agreement. J-PAL SA will not take any legal action against the Enrollee if one or more responsibilities remain unfulfilled under the agreement.

ACCEPTED BY:	ACCEPTED BY:
J-PAL SA	Enrollee
Signature	Signature
Name	Name
Location	Location
Date	Date

Survey questions used in constructing indices for heterogeneous treatment effects

This section details the (pre-specified) survey questions used in constructing the indices for heterogeneous treatment effects.

Financial constraints

1) If you needed to spend ₹5000 for agricultural equipment, would you have savings to draw on?

2) If you needed to spend ₹10,000 for agricultural equipment, would you have savings to draw on?

3) If you needed to spend ₹5000 for agricultural equipment, how easy would it be for you to get a loan for that amount?

4) If you needed to spend ₹10,000 for agricultural equipment, how easy would it be for you to get a loan for that amount?

These (standardized) variables are used to create an index, which is used to create a binary variable split at the median to denote high financial constraints.

Distrust

1) Generally speaking, would you say that most people can be trusted or that you need to be very careful in dealing with people?

2) I'd like to ask you how much you trust people from various groups. Could you tell me for each whether you trust people from this group completely, somewhat, not very much or not at all?

    - People in your neighborhood?
    - Strangers?

3) Even if you have had very little or no contact with these following institutions, please base your answer on your general impression of these institutions.

    - The Punjab Government?
    - The village Panchayat?
    - The cooperative society?
    - Non-governmental organizations (NGOs)?
    - Financial Institutions like Banks/Insurance Companies?

CRM access barriers indices

We construct three indices to measure different aspects of CRM equipment access barriers. The first measures information constraints, the second access barriers, and the third beliefs about how CRM equipment impacts agriculture relative to burning. All questions except the first are asked about the CRM equipment farmers reported being familiar with.

Information Constraints

1) Do you know about any crop residue management techniques to manage paddy stubble?
2) Where can you rent it (CRM equipment) from?

Access Barriers

1) Do you own [CRM equipment] as an individual or member of a CHC or Coop?
2) Is using [CRM equipment] more expensive or less expensive than burning paddy stubble?
3) In days, how long would it take you to access crop residue management equipment for managing paddy stubble at harvest time this year?
4) Including all costs, how much would the equipment cost per acre (in Rs.)?
5) How many days would it take to manage paddy stubble using this equipment?

Negative Beliefs About CRM Equipment

- Is using [CRM equipment] better for long-term soil health or worse for soil health than burning paddy stubble?
- Does using [CRM equipment] help yield of rabi season or hurt yield of rabi season compared to burning paddy stubble?

Remote sensing model

This section provides additional detail on the construction of our remote sensing based outcome. For a complete description, please see Walker et al. (2022).

Model background

The goal of the model is to detect whether a plot in our sample was burned at any point during the burn season (from October 10 to December 15, 2019) based on satellite imagery. While burn scars are obvious if the plot is observed by satellite soon after burning, this signal erodes quickly with time. With a temporal resolution of about two days, PlanetScope imagery can often capture burned plots within this critical window. However, clouds and other abnormalities result in a maximum gap between any two images of 8 days on average across plots in our sample. While Sentinel-2 imagery has a coarser temporal resolution of about eight days, it provides mid- and short-wave infrared (SWIR) bands that are able to detect signals of burning for a longer window post-burn. By combining observations from both sensors, we built a Random Forest (RF) model with an overall accuracy of 82% in detecting burning in smallholder rice plots.

Other studies have relied on burn detection based on active fires, using, for example, data from the Visible Infrared Imaging Radiometer Suite (VIIRS). The sensor has a spatial resolution of 375m, resulting in pixels that are around 140,000 m^2. A typical plot in our sample is around 10,000 m^2, and only a small share of farmers in a village are enrolled in the study, so existing active fire products are poorly suited to our measurement goals.

An overview of image processing for both types of satellite is as follows:

Imagery and image processing overview:

- PlanetScope: Four-band harmonized surface reflectance product from PlanetLabs
  - Resolution: Spatial: 3m, Temporal: 2.2-day on average (30-40 images per pixel)
  - Spectral bands: blue, green, red, Near Infrared (NIR)
  - Clouds: only included images with <10% cloud cover. Remaining clouds were masked using the unusable data masks (UDM2) provided with the imagery.
  - Pre-processing: atmospheric correction based on the 6SV2.1 radiative transfer code already applied to product. Harmonized product also incorporates data from Sentinel-2 to normalize the spectral response functions between sensors.
- Sentinel-2: Level-1C products from USGS, converted to surface reflectance
  - Resolution: Spatial: 10m for visible and NIR bands, 20m for shortwave infrared (SWIR) bands. Temporal: 7-8 days on average
  - Spectral bands: Blue, Green, Red, NIR, SWIR1, SWIR2

- Clouds: Cloudless layers from Google Earth Engine with cloud probabilities $\leq$.5 cloud were used as initial masks, then inspected and expanded manually to remove remaining cloud shadows.
- Pre-processing: Geometric and radiometric corrections applied as Level-1C product, converted to bottom-of-the atmosphere reflectance with SNAP toolkit.

Feature creation and selection:

As model inputs, we used individual bands and derived indices aimed at reducing noise and amplifying the portion of the spectrum most associated with burning. These indices were taken from the literature on burn mapping with a focus on char detection rather than vegetation change, as our primary separation task is between bare soil (harvested and often tilled plots) and charred soil (burnt plots). For PlanetScope images, we used the Bare Soil Index (BSoI), which uses all four bands, the Char Index (CI), which uses all visible bands, and the Burn Area Index (BAI), Simple Ratio (SR) and NDVI, which use the red and NIR bands. For Sentinel-2 images, we also included several bands using one or both SWIR bands including the Burn Scar Index (BSI), Mid-Infrared Bispectral Index (MIRIBI), and two variations of the Normalized Burn Index (NBR and NBR2). See Walker et al. (2022) for background and equations.

We stacked all images that overlap with any of the study participants' rice plots into a time-series and created pixel-level features based on statistics from each band and index across time. Statistics included min, max, median, and outer percentiles. An additional temporal differencing measure (Vdiff) was calculated for each band and index with the goal of capturing the moment the pixel changed from unburned to burned. This Vdiff measure was calculated based on the largest drop (or spike) in the sequence of values (V) for V_{t+1} - V_t. We used SequentialFeatureSelector in the sklearn toolkit in Python to reduce the feature space to an optimal number of features (around 30) prior to the final analysis. Retained features are presented in Walker et al. (2022).

Recognizing that pixels along the edge of a plot likely present differently due to the mixture of plot/non-plot classes and different burn patterns at edges, we flagged border pixels. These pixels were observed to have low importance in the construction of the RF model and were thus dropped from our analysis.

Model training and assessment:

Training data consists of 441 burned and 240 unburned labels collected on the ground from participant farmers in 2019. Unburned labels come from plots where participants invited a monitor to visit to confirm that the stubble was managed without burning. Burned labels come from observations during unannounced spot checks of participant plots.

We used pixel-level features from the 681 labeled plots to train a RF model to provide burn predictions. Although data was retained at the pixel level, full plots were held out from the training data for use in optimization and accuracy assessment. Plot-level holdouts were necessary because pixels within the same plot have highly correlated features; if some

pixels within a plot were used for training while others were used for testing, overfitting of the model and overestimation of accuracy would occur. A single plot was held out each time while a RF model was generated with the remaining 680 plots. This process was repeated 680 times in a Leave-One-Out Cross-Validation (LOOCV) format. Model accuracy was assessed based on the prediction score for each plot in the run where it was left out of model training.

To convert from pixel to plot-level predictions, we aggregated on the plot-level mean of the continuous RF output (we also tried the median and various percentiles and found the mean to perform best). We then used two approaches to set the classification thresholds based on this mean score, with plots exceeding the threshold classified as burned. First, we maximized overall accuracy ("maximum accuracy") by iterating over each threshold percentile and selecting the threshold with the highest accuracy for the full labeled set of plots. Alternatively, to balance accuracy across burned and not-burned labels ("balanced accuracy"), we iterated the burn accuracy and the no-burn accuracy over each threshold percentile, interpolated these accuracies into smooth functions, and selected the percentile threshold with the greatest accuracy for the mean at the point of intersection (where burned accuracy equals unburned accuracy). We tested using Cohen's Kappa for threshold optimization, which measures how a classifier compares when evaluated against a random classifier. In this case, maximizing kappa resulted in the same threshold selection as the maximum accuracy approach for all versions of our model.

Following plot-level aggregation, our best RF model achieves 82 percent overall accuracy, with 91 percent accuracy in detecting burned plots but only 63 percent accuracy in detecting unburned plots (details in Walker et al. (2022)). When the burned/unburned errors are balanced with our balanced accuracy procedure, the overall accuracy is reduced to 78 percent. See Table A11.

The RF model is trained using negative labels that are only available for the treatment group (and positive labels for both treatment and control groups). This could introduce bias into the classification if the spectral signature of not-burning is affected by treatment; if not-burning looks the same in treatment and control, this is not an issue. As one check on potential bias, Figure A5 shows the distributions of the continuous random forest model output using plots not in the training set. Both for plots classified as burned and those classified as not-burned, the distributions are similar in the treatment and control groups. Formal statistical tests for equal distributions, conditional on classified burning status, confirm that there is no statistical difference.

Table A11—: Remote Sensing Model Accuracy in Holdout Sample

Accuracy model:	Unburned	
	Maximum Accuracy (1)	Balanced Accuracy (2)
Mean accuracy	0.82	0.78
False burn	0.13	0.08
False no burn	0.05	0.14
True burn	0.59	0.51
True no burn	0.22	0.27
No burn accuracy	0.63	0.76
Burn accuracy	0.92	0.79

Note: Accuracy statistics for remote sensing measures of burning, using different classifications thresholds. The true/false burn/no-burn rows show counts of the number of plots in each category. $N = 681$.

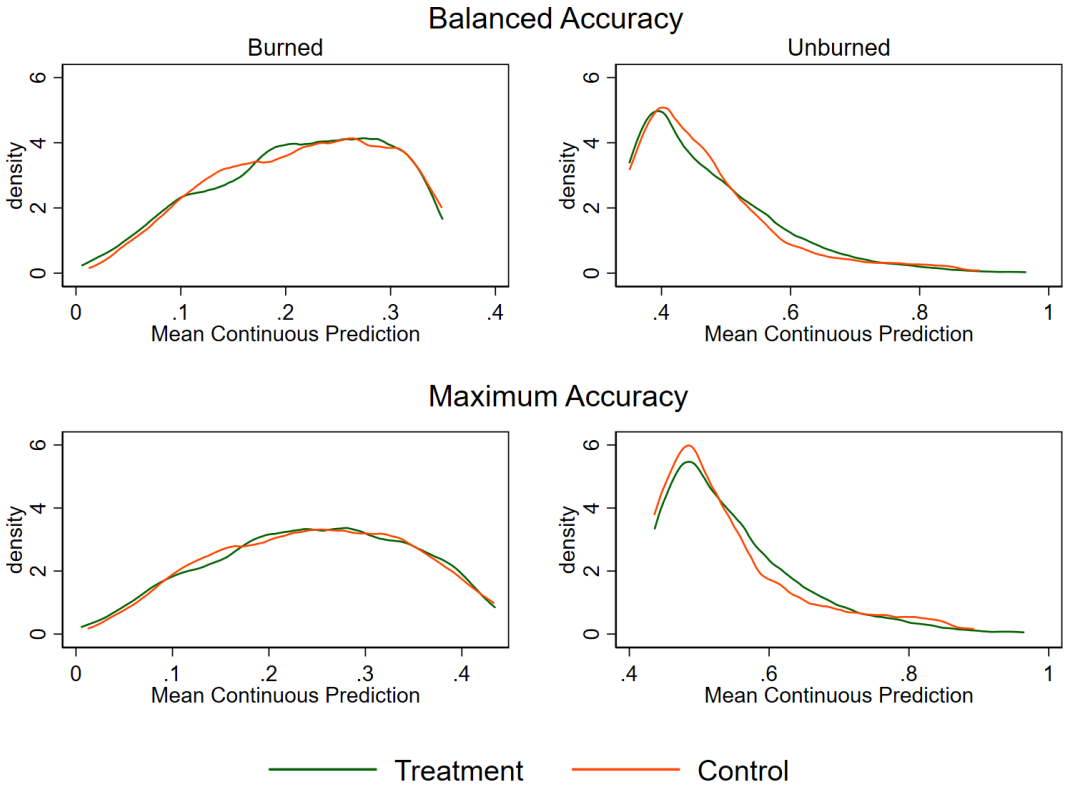


Figure A5. : Distribution of Random Forest Predictions by Treatment

Note: The left panel shows the distribution of the continuous remote sensing measure of not-burning for the plots classified as having been burned. The right panel shows the distribution of the same measure for plots classified as not having been burned. The continuous remote sensing measure ranges from 0 to 1, where higher values mean that it is more likely that the plot has not been burned.

COST-BENEFIT CALCULATIONS

	Value	Details	Source
Deaths per year	36,980	86,000 total in 2018, 43% from Punjab. 2018 numbers, see table in supplement 5.	Lan et al. (2022)
Value per life, lower	688,000	640k in 2016 dollars (using 2016 exchange rate), converted to 2018 dollars using India's inflation rate	Majumder and Madheswaran. (2018)
Value per life, upper	5,800,000	800K in 1990 dollars, converted to 2018 (1990 exchange rate, India-specific inflation)	Madheswaran (2007)
Acres of non-basmati paddy in Punjab	6,011,980	2018 kharif non-basmati area, converted from ha	APEDA (2018)
Percent burned	0.66	2018-19 number	Kumar et al. (2019)
Acres burned	3,967,907		
Total mortality damages, Punjab burning	25,442,240,000		
Value per acre burned, lower in USD	6,412.01		
Value per acre burned, lower in Rupee	512,960.44		
USD upfront cost per acre (max)	50.63		
USD upfront cost per acre (balanced)	33.69		
Ratio of benefits to costs (max)	126.66		
Ratio of benefits to costs (balanced)	190.34		
Lives saved per acre	0.0093		
Cost per life saved, max	5,432.00		
Cost per life saved, balanced	3,614.63		

*Note that we are using 80 rupee per dollar, all 2018 values.

References

APEDA. (2018). Basmati Survey –Final Report-6 (Season 2018). Geotrans Technologies Pvt. Ltd. https://apeda.gov.in/apedawebsite/Announcements/Basmati_Crop_survey_Report_6_Season_2018.pdf

Kumar, P., Rajpoot, S. K., Jain, V., Saxena, S., & Ray, S. S. (2019). Monitoring of rice crop in Punjab and Haryana with respect to residue burning. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *42*, 31-36.

Lan, R., Eastham, S.D., Liu, T. *et al.* Air quality impacts of crop residue burning in India and mitigation alternatives. *Nat Commun* **13**, 6537 (2022). https://doi.org/10.1038/s41467-022-34093-z

Madheswaran, S. (2007). Measuring the value of statistical life: estimating compensating wage differentials among workers in India. *Social indicators research*, *84*, 83-96.

Majumder, A., & Madheswaran, S. (2018). *Value of statistical life in India: A hedonic wage approach*. Institute for Social and Economic Change.