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Lessons & Learnings of Crop Residue Management on the Field

Annual Assessment for the Agricultural Year: 2023-24

October 2024

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Report authors: Mohit Sharma, Ishan Sahajpal, Nitish Sharma

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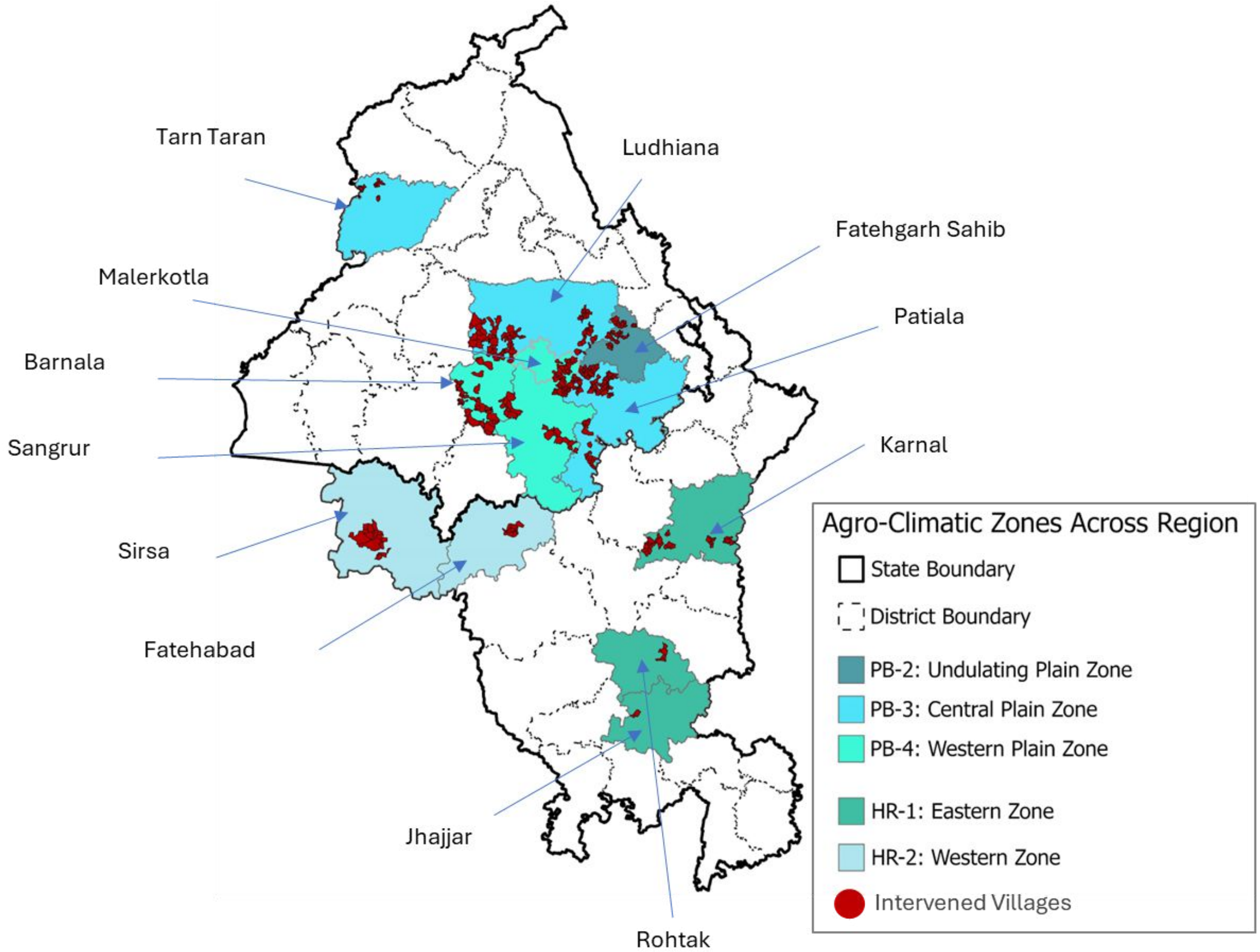
1. Background

The **Cleaner Air Better Life Crop Residue Management (CRM) Programme** started as a pilot intervention in 2018 in 19 villages in two districts of Punjab as a follow-up to the **CII-NITI Aayog 'Action Plan for Biomass Management'** (CII-NITI Aayog 2018). It has since expanded to 793 intervened villages across 13 Districts of Punjab and Haryana in 2024 to mitigate open agricultural burning which is a decades-old or conventional practice used by farmers in region to prepare land for sowing wheat and pest control from the previous rice crop.

Figure 1.1: **Intervened villages in the agricultural year 2023-24**

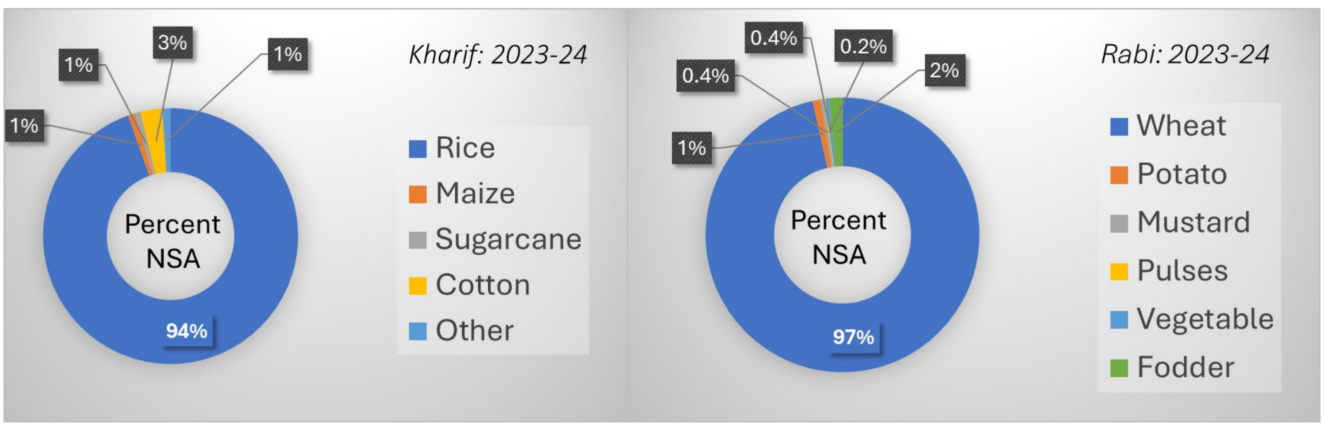


Source: CII Cleaner Air Better Life (2024)

This study presents a *detailed scientific assessment of 432 intervened villages in Winter of 2023 across 12 Districts of Punjab and Haryana region basis the impact matrix developed inhouse* (CII CABL 2022). The geographical boundaries of these 432 intervened villages can be seen in Figure 1.1 and the intervention spans across four agroclimatic zones of the two states (ICAR 2020). All of these areas, albeit, share one common characteristic- predominant cultivation of rice crop or the rice-wheat cropping system. (details of different crops grown in intervention areas as captured in the baseline study are summarised in the Figure 1.2).

All intervention areas (except Jhajjar as shown in Figure 1.1 & Table 1.1) are hotspots for rice stubble burning in winter months (IARI 2024) and multi-pronged intervention at CII Cleaner Air Better Life caters to all major needs of farmers- 1. capacity or know-how, 2. training, 3. tools, 4. farm advisory by pooling available resources at the farmer cooperative level (typically 3-4 villages) and bringing support from the private sector to fill gaps. The intervention has led to a **sustained community-level shift**, as assessed and documented in this report along with major environmental and socio-economic impacts emanating from the intervention and adoption of sustainable practices that do not involve burning of crop residues. It is worth noting that recent Central and State of India policies/schemes (GOI 2023), since release of the CII-NITI Action Plan Biomass Management in early 2018, focused on both in-situ and ex-situ management of rice straw have been quite effective in reducing the extent of these farm fires in the region. This is based on the year-on-year evidence from baseline study in newly intervened areas as discussed in section 3 which shows us that share of burning as a a predominant CRM method has come down from approximately 90% in 2018 to 50% in the last couple of years including agricultural year 2023-24.

Figure 1.2: Share of different crops grown in intervened region



Source: CII Cleaner Air Better Life (2024) Analysis

Table 1.1: Details of Intervened rural clusters of Punjab & Haryana Region

S. No.	State	District	Year-wise Intervened Villages						Intervened Villages	Net Sown Area	Farmers Intervened
			2018-19	2019-20	2020-21	2021-22	2022-23	2023-24			
	name	name	number	number	number	number	number	number	number	acre	number
1	Punjab	Barnala	...	...	...	...	15	29	44	1,12,977	21,957
2		Fatehgarh Sahib	...	...	...	...	37	...	37	24,930	2,494
3		Ludhiana	7	25	22	...	...	50	104	1,17,403	13,981
4		Malerkotla	...	...	21	...	2	20	43	36,845	4,937
5		Patiala	9	47	17	...	...	16	89	6,8097	11,934
6		Sangrur	...	...	...	...	9	16	25	34,500	5,365
7		Tarn Taran	...	...	...	13	...	...	13	6,860	783
8	Haryana	Fatehabad	...	4	1	7	...	...	12	12,490	1,910
9		Jhajjar	...	...	...	3	...	...	3	3,900	1,050
10		Karnal	...	...	...	30	...	...	30	34,812	9,880
11		Rohtak	...	2	4	...	...	...	6	11,100	4,035
12		Sirsa	...	8	5	8	...	5	26	33,770	6,795
Total			**16**	**86**	**70**	**61**	**63**	**136**	**432**	**4,97,684**	**85,121**

Source: CII Cleaner Air Better Life (2024)

Note-

1. *Total of 423 villages out of 432 intervened villages in 2023 are assessed in this study in 2024 and six villages of Jhajjar and three from Rohtak clusters were not surveyed due to operational constraints.*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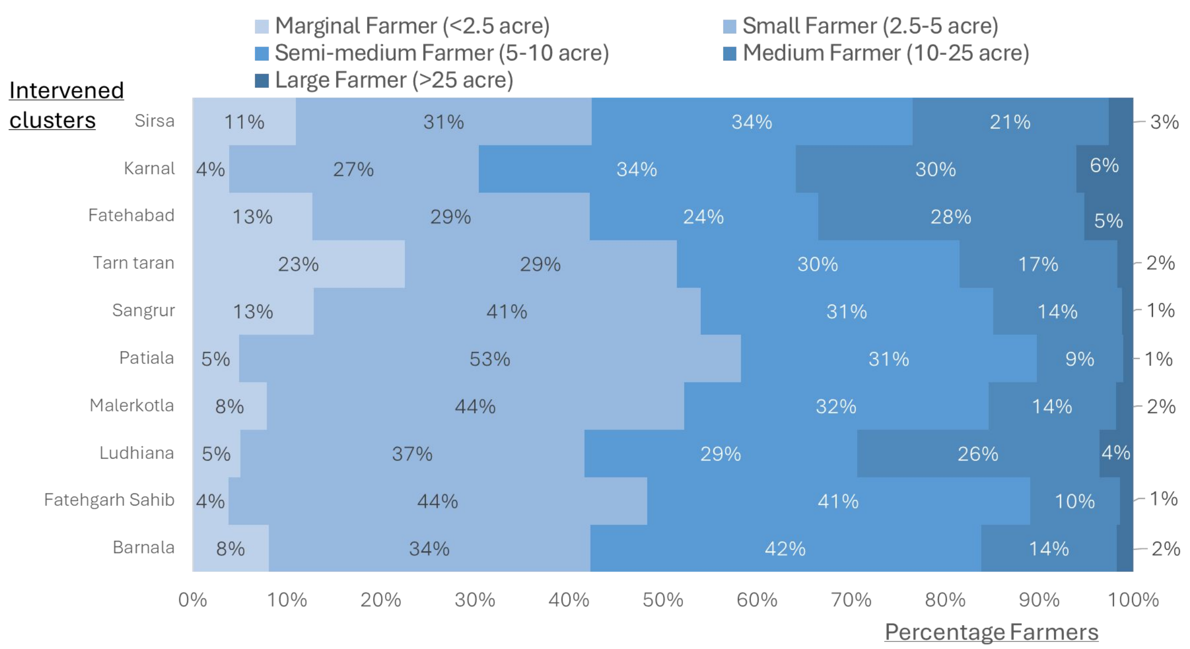
2. Methodology

The environmental and socio-economic impacts of CABL intervention are quantified based on analysis of actual activity data of farmers in intervened areas. Farmer activity data is collected by team of field volunteers three times in a year and the overall study is divided into three parts which include-

1. Pre-intervention **baseline study** which includes data points (1814 farmers samples in 2023-24) on cropping patterns and existing farming practices
2. Post-intervention **impact assessment** study as a follow up to implementation in October and November months and includes activity data (2444 farmers samples in 2023-24) for farming practices adopted in harvesting rice and sowing wheat
3. Detailed **agronomy study** right after they have harvested wheat so that all farm inputs and productivity for the whole agricultural year can be evaluated for farmers (1693 samples in 2023-24) adopting different sets practices for managing post harvest remains of the rice crop under the CABL intervention

While total 5951 samples were collected for annual assessment in agricultural year 2023-24 , total 24,500 samples have been collected for evaluating the field scenario in the intervention areas so far and building the overall picture as detailed in the next section (CII CABL 2019, 2020, 2022)(Section 3). It is a constant endeavor of the Team to keep margin of errors as low as possible (less than 5%) and making sure that diverse communities in rural clusters are adequately covered. All the results are duly vetted in the process with focused groups discussions at the Farmer cooperative society level, supplemented with understanding from extensive field visits and telephonic calls with farmers for checking any anomalous data points. The distribution of farmer samples as collected in the agriculture year 2023-24 across intervened clusters and farmer size classes is shown in Figure 2.1.

Figure 2.1: Details of Intervened rural clusters of Punjab & Haryana Region



Source: CII Cleaner Air Better Life (2024) analysis of primary data from field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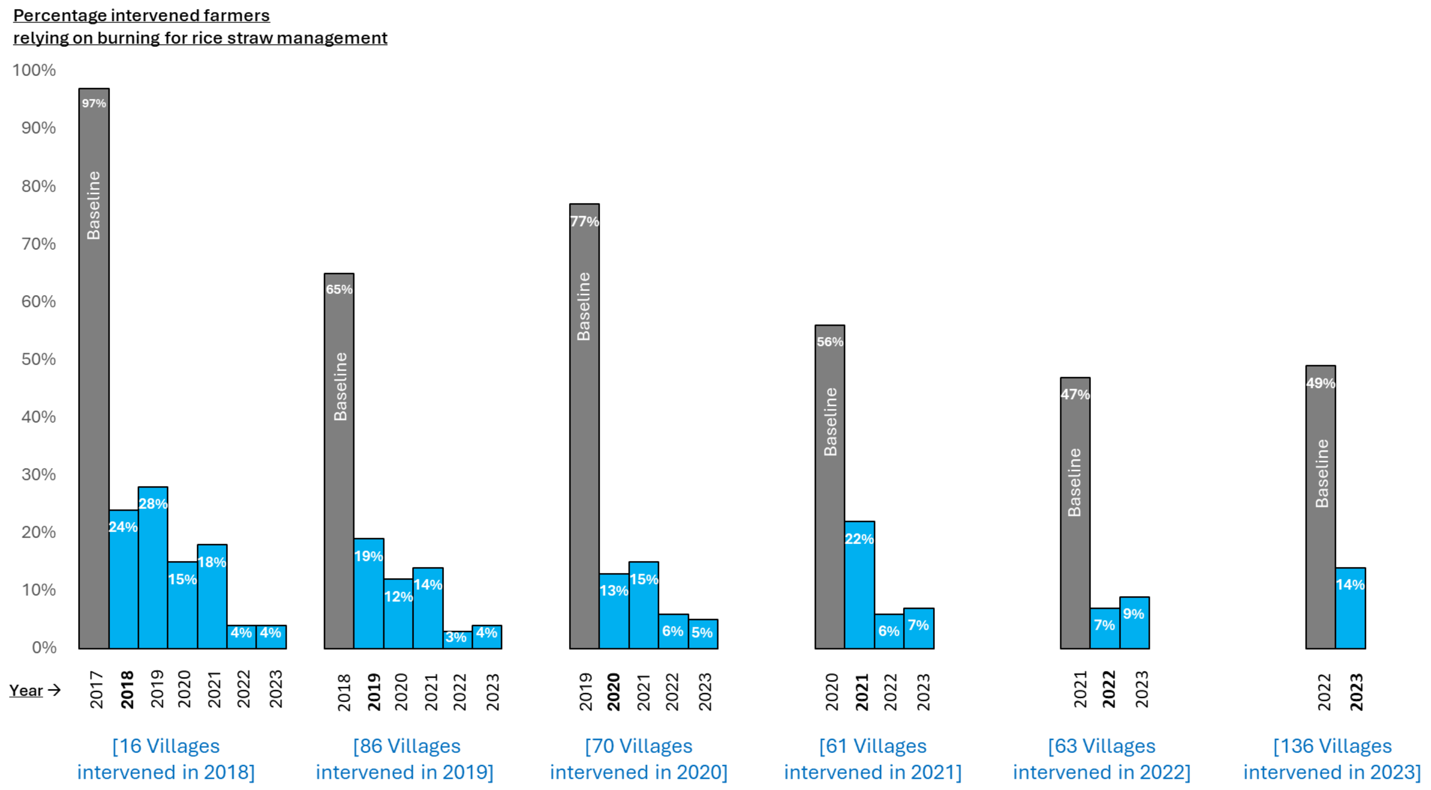
3. Sustained Mitigation of Agricultural Burning

The programme led to sustained mitigation of crop residue burning over six years of intervention and has been able to converge farmers at the community level for sustained shift to practices that do not involve burning in management of post-harvest remains of the rice crop.

Figure 3.1: **Sustained mitigation of crop residue burning across six-years of CII CABL intervention**



Source: CII Cleaner Air Better Life (2024) analysis of primary data from field

Note-
1. Crop residue here refers to the post-harvest remains of rice crop which remains critical for regional air quality during winters.
2. While there is a clear spillover impact of practices adopted in kharif season to rabi season based on the field data, this is not captured in above results which is a rather conservative estimate of results on the field.

Key results of annual assessment studies conducted over last six years are plotted in Figure 3.1. The figure depicts extent of burning of rice straw before and after intervention and results are grouped here for set of villages adopted or intervened in each year. Following key conclusions can be drawn from these results-

1. There is clear trend in the figure 3.1 which shows that burning has progressively declined each consecutive year in the intervention areas. The oldest adopted villages show lowest level of burning at 3-4%.
2. For newly intervened villages the level of burning came down to roughly 15-25% in the first year of intervention
3. **It takes about 2-3 years for intervened villages to be burning-free** (which practically means less than 5% farmers still relying on burning at community-level) and **become a model village or village cluster for nearby rural areas**.
4. The baseline burning levels have significantly come down over these six years from average 97% intervened areas in 2018 (CII CABL 2019) to less than 50% in recent years. This shows that there has been definitive improvement in farmers awareness and capacity in the region to adopt sustainable crop residue management methods.

Box 3.1 Mulching Rice Straw

Retaining Rice Straw on Field Surface

Step-1. Retaining Rice Straw on Field Surface: First set of operations to retain rice straw on the field surface as mulch. This step may include- 1. chopping standing stubble & evenly spreading rice straw during harvesting as realised on field with super-SMS mounted on a combine harvester 2. chopping standing stubble and loose rice straw after harvesting as realised on field with tractor-mounted tool such as mulcher as seen in the picture here.

Step-2. Sowing Wheat Crop without Tilling: Step to drill wheat seeds directly through the mulch surface, using specialised sowing tools such as a happy seeder or smart seeder. This is a bare minimum step required for the method (refer tool combinations 3.1 & 3.2 in the table 5.1)

Sowing Wheat Crop without Tilling

Rice Straw Mulched Wheat Field

Rice Straw Mulched Field: Picture shows the final field preparation with rice straw mulch layer immediately after sowing wheat

Box 3.2 Rice Straw Incorporation

Step 1. Field Preparation: the step typically involves a combination of tool runs to prepare field for sowing the next crop. It may include- (1) chopping standing stubble, shredding loose straw and evenly spreading the biomass (say, using a mulcher) as seem in the step 1 of mulching in Box 4.1 -or- (2) deep ploughing the field (say, using an MB plough) as seen in the picture to incorporate rice straw in this step itself

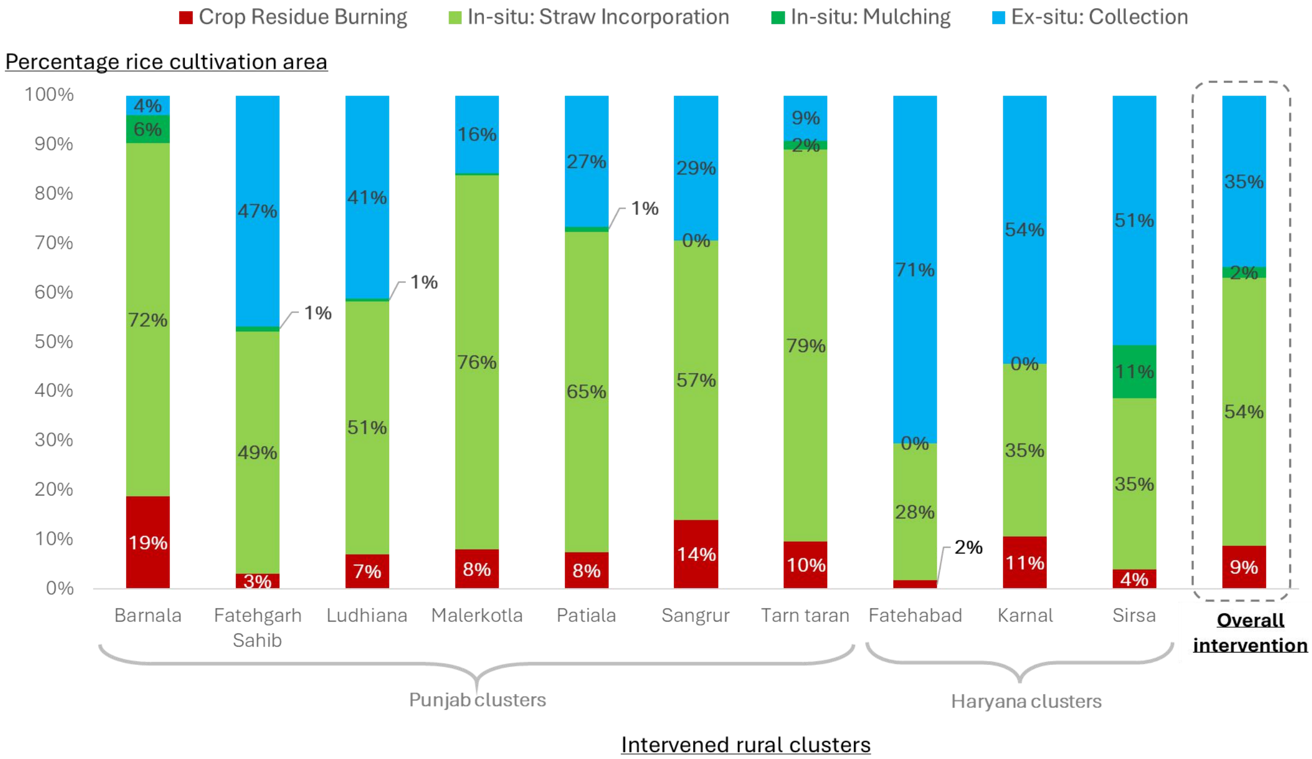
Step 2. Sowing Wheat: using a specialised tool such as a rotavator with seed drill or super seeder to incorporate rice straw while sowing wheat seeds

Picture shows the rice straw incorporated field immediately after sowing wheat. Four key tool combinations (See 4.1-4.4 under Table Table 5.1) utilised for straw incorporation are summarised in section 5.

4. Accelerated Adoption of Sustainable Practices

Sustainable and proven alternatives as adopted in intervened areas in participatory planning with rural communities include- (1) mulching (2) straw incorporation (3) collection and baling. As part of this assessment, a great deal of emphasis is placed on understanding evolution of these practices in intervened communities as environmental benefits vary widely across methods and well as specific tools combinations as detailed in this section.

Figure 4.1: **Share of different CRM practices across intervened rural clusters[1]**



Source: CII Cleaner Air Better Life (2024) analysis of primary data from field

Cluster-wise results from our detailed assessment are plotted in Figure 4.1 above. Following key conclusion can be drawn form here based on this and understanding from the field -

1. **Share of conventional practice of rice straw burning practice is limited to 10% across majority of intervened clusters** in AY 2023-24 except in Barnala, Sangrur in Punjab and Karnal in Haryana which are relatively new clusters under the CABL Intervention.
2. Clearly, the adoption of mulching has declined significantly across all clusters at the rate of soil incorporation which remains the most adopted practice across clusters. Sirsa is only exception to this, where mulching shares significant share among CRM practices at 11% due to specific soil type- sandy & loamy soils, that support mulching.
3. Adoption of soil incorporation is mainly driven by key behavioral factors such as- (a) convenience in operation, (b) farmers' risk perception with methods and (c) aesthetic reasons or familiarity in field preparation (to conventional method involving extensive tillage). See Figure 4.2 for more details on the point 3.c.
4. While share of straw incorporation of ranges from 49-79% in Punjab and 28-35% in Haryana, the adoption of ex-situ management has grown significantly as high as 47% in Punjab and as high as 71% in Haryana clusters which is fueled by efforts from both Central & State Governments and rural entrepreneurs (GOI 2023, GoHR 2023).

[1] Assessed in ten out of twelve intervened districts in 2023-24 except 9 villages in Jhajjar & Rohtak

Figure 4.2 **Land Preparation under Different In-situ Management Methods**

(A) In-situ management: **Straw Incorporation**

(B) In-situ management: **Mulching**

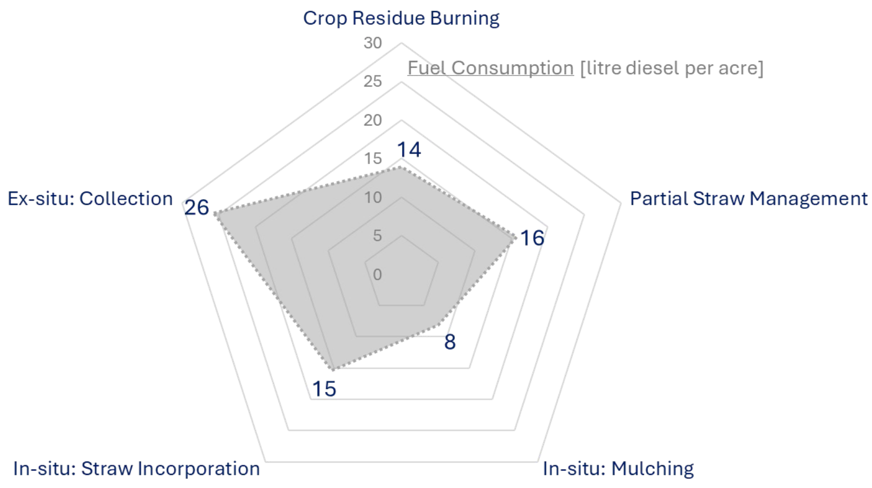
key assessment on mitigation of crop residue burning & adoption of alternatives, as detailed in sections 3 and 4, the CABL intervention in AY 2023-24 yields following overall impact assessment figures-

1. Total **94% of all intervened farmers (85,121) adopted sustainable rice straw management practices** in the AY 2023-24 or the intervention year 2023
2. Rice straw **burning was avoided on 91% of the intervened area** (4,97,684 acre Net Sown Area for the rice crop) leading to approximately 11 lakh tonnes of rice straw saved from burning in AY 2023-24
3. As per the baseline figures from the previous AY 2022-23, this amounts to **71% reduction in farm fires** and **69% increase in adoption of alternatives to burning in the AY 2023-24**

5. Fuel Consumption: A Key Criterion for Sustainability

Fuel consumption is a key driver that not only defines environmental sustainability of CRM methods, but also dictates overall economics on the field. The Figure 5.1 provides a summary of our findings on fuel consumption (for operating tractor-mounted farm implements or agri tools) of different practices at the field. It is worth noting that these figures are specific to our intervention areas and represent average figures across practices based on share of major tool combinations in these areas. These major tool combinations, which serves as basis for these figure, are further captured in the Table 5.1. This is primarily owing to the fact that mechanical energy needed to mulch or incorporate straw in the field will vary depending on local contextual factors such as- quantum of straw, crop variety, soil type, agro-climatic zone etc.

Figure 5.1: **Fuel Consumption across CRM Practices**



Source: CII Cleaner Air Better Life (2024) analysis of primary data from field

As mulching entails sowing of next crop (wheat) by drilling seeds on top of mulch (rice straw) layer without the need of extensive tillage, it is the most environmentally sustainable and cost-effective method for rice straw management and the only method with fuel consumption that is lower than the conventional method, that is crop residue burning following by extensive tillage to sow the next crop (See Table 5.1 for more details). It's declining share in recent years remains a key concern. While rice straw incorporation consumes roughly double the energy, energy consumption associated with baling is nearly triple when compared to mulching. This is again due to mechanical effort in mixing (top soil and straw) involved in straw incorporation method and additional efforts needed for baling out the straw from field in ex-situ methods.

Table 5.1: Major tool combinations and their share across CRM practices & methods

Practice	Method		Tool Combinations	Percentage Share in Method
Conventional Practice	1. Crop Residue Burning	1.1	Cutter + Open Burning + Super Seeder	75%
		1.2	Cutter + Open Burning + Disk Harrow + Cultivator + Leveler + Zero-Till	14%
		1.3	Cutter + Open Burning + Rotavator-cum-SD	11%
Hybrid Practice: Partial Straw Management	2. Partial Straw Management	2.1	Burning excess straw + Super Seeder	64%
		2.2	Burning excess straw + Super Seeder (2x)	15%
		2.3	Burning excess straw + Rotavator	12%
		2.4	Burning excess straw + Rotavator (2x)	7%
		2.5	Burning excess straw + Disk Harrow + Cultivator + Leveller + Rotavator-cum-SD	2%
Alternate Practice: In-situ Management	3. Mulching	3.1	Happy Seeder	73%
		3.2	Smart Seeder	18%
		3.3	Mulcher + Happy Seeder	9%
Alternate Practice: In-situ Management	4. Straw Incorporation	4.1	Super Seeder	82%
		4.2	Super Seeder (2x)	9%
		4.3	Rotavator-cum-SD (2x)	5%
		4.4	Rotavator-cum-SD	4%
Alternate Practice: In-situ Management	5. Collection/ baling	5.1	Cutter + Raker + Baler + Super Seeder	72%
		5.2	Cutter + Raker + Baler + Disk Harrow + Cultivator + Leveller + ZT Drill	15%
		5.3	Cutter + Raker + Baler + Rotavator-cum-SD	9%
		5.4	Manual collection + Super Seeder	4%

Source: CII Cleaner Air Better Life (2024) analysis of primary data from field

6. Environmental Benefits

Under the CABL intervention, total 28.5 lakh tonne of rice straw has been avoided so far from burning and as a result of the large scale adoption of in-situ management practices- 20 Lakh tonne lakh tonne organic matter has been recycled back to soil under CABL intervention. This amounts to significant mitigation in air pollution from crop residue burning which is a major regional source of air pollution across the Indo-Gangetic Plains (Singh et al 2020).

Box 6.1 Environmental Benefits of the CABL Intervention

	Impact areas	Benefits/ savings Cumulative: 2018-2023	AY 2023-24
1. Clean Air	**1.1 Air pollution in Particles** a. Coarse particles: PM_{10} b. Fine particles: $PM_{2.5}$	13.3 million kg PM10 12.1 million kg PM2.5	5.1 million kg PM10 4.7 million kg PM2.5
	1.2 Air pollution in Gases a. Oxides of Sulphur (SO_x) b. Oxides of Nitrogen (NO_x) c. Volatile Organic Compounds (VOCs) d. Ammonia (NH_3)	**28.1 million kg Gases**	**10.9 million kg Gases**
2. Climate Co-benefits	**2.1. Non-CO_2 greenhouse gases/GHGs** **2.2 Black Carbon (BC)**	**630 million kg CO2-eq** **1.3 million kg BC**	**240 million kg CO2-eq** **0.5 million kg BC**
3. Water conservation	**3. Groundwater in agriculture**	148 million cubic metre	52 million cubic metre

Source: CII Cleaner Air Better Life (2024) analysis of primary data and analysis based on Shrestha et al (2012), IPCC Sixth Assessment Report (2021), Kumar et al (2015), Lohan et al (2017), Singh et al (2018)

Key benefits of the CABL intervention as quantified under relevant environmental impact categories are summarised in the Box 6.1 above. In addition, to these significant benefits on clean air, climate change and water conservation fronts, 670 million kg carbon is diverted for soil sequestration under his intervention. Recycling of carbon and other nutrients (NPK) led to healthier soils and significant enhancement in farmers productivity which are documented in the upcoming sections focused on socio-economic benefits of sustainable crop residue management and lessons for the field.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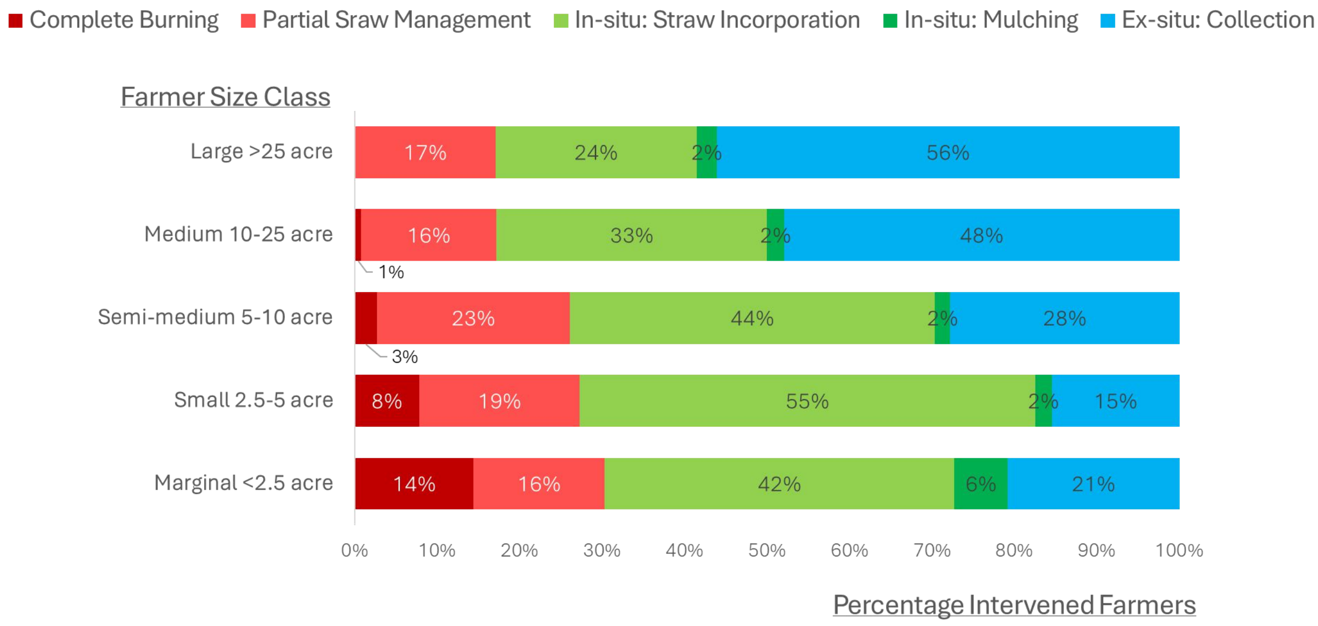
7. Inclusive Adoption of Alternative Practices

The Programme's aim is to deliver solutions that are technically feasible and cost-effective to all farmers. In this section we evaluate intervention results specifically from social lens by looking at adopted practices across all farmer size classes.

Figure 7.1: Adoption of CRM Practices in Intervened Areas by Farmer Size Classes



Source: CII Cleaner Air Better Life (2024) analysis of primary data from field

As clear from analysis of farmers' primary data, plotted in Figure 7.1, sustainable farming practices got significant traction across farmer size classes in the rice post-harvest season of 2023. Also as evident from the field data above and our best understanding from the field, following key finding can be summarised-

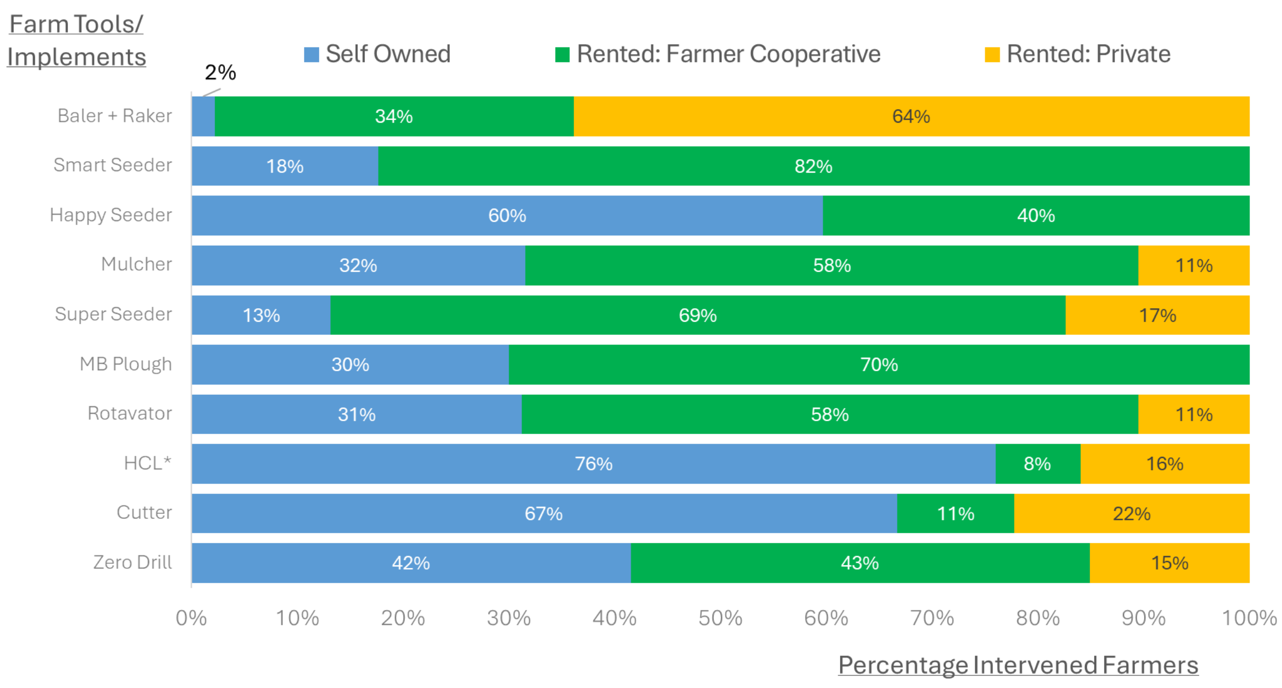
1. Baling has gained significant traction among large and medium sized farmers with landholding above 10 acres and 48-56% of these farmers adopted baling in 2023. Affordability of baling or ex-situ management still remains a major concern for the small and marginal farmers. Beyond, purely the cost concerns, baling also remains restrictive in small plots.
2. Driven by convenience and similarity in field preparation for the next crop, soil incorporation retains the largest share of all practices among semi-medium, small and marginal farmers where its share ranges from 42% to 55%.
3. Mulching, despite its proportionately lower overall share amongst all alternate practices, finds relatively more traction with marginal farmer, as it is the most cost effective crop residue management method of all and requiring minimal amount of top soil disturbance and hence the energy or fuel consumption.

8. Shared Economy for Crop Residue Management

Creating a shared economy for needed tools is crucial part of CABL intervention as these tools will only be required by farmer for a couple of days in a year. The CABL intervention is anchored at farmer cooperatives societies many of whom already operates tool banks in their clusters and this is where viability gap in needed tool for a village cluster is addressed by the intervention. The Figure 8.1 captures the field scenario from our annual assessment for farmers' access to tools available under various channels including those under shared economy model as strengthened by the CABL intervention at the farmer co-operative level. As evident from the Figure 8.1, on average 64% of intervened farmers utilised in-situ management tools through community tool banks including- superseeder (69%), happyseeder (40%), MB plough (70%), mulcher (58%), smartseeder (82%) etc. In contrast, availability of balers under shared economy still remains limited at 34% due to high capital and maintenance costs. It is worth noting that total 625 number of farm implements have been provided by CII Foundation in intervened areas so far which include 6 balers.

In addition to private sector resources brought by the CABL intervention, the Central Government schemes for promotion of in-situ management is also a significant factor driving the shared economy model in the region (GoI 2023). Growing demand for new tools like super seeder has also improved the penetration of high HP tractors among medium and large farmers who supplement their income by providing these tools as service.

Figure 8.1: Sources of Farm Tools or Implements for the Intervened Farmers



Source: CII Cleaner Air Better Life (2024) analysis of primary data from field

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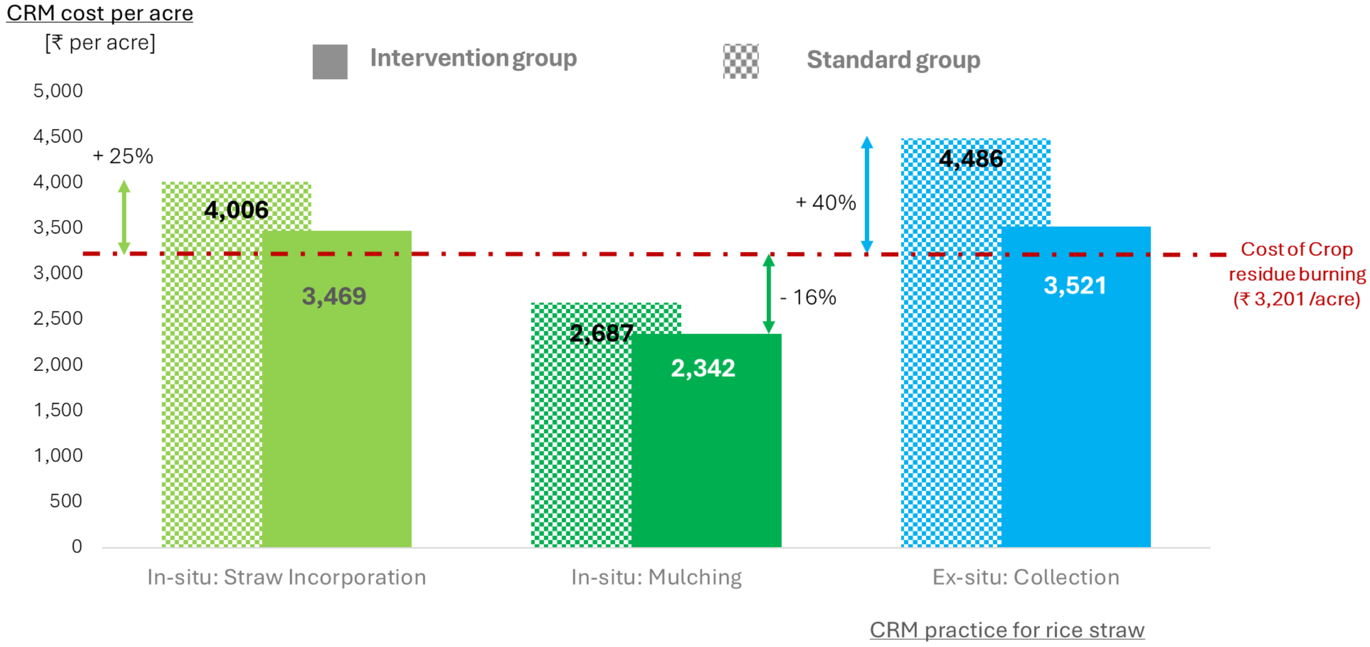
9. Cost of Crop Residue Management

Figure 9.1: **Assessing Cost of Crop Residue Management**



Source: CII Cleaner Air Better Life (2024) analysis of primary data from field

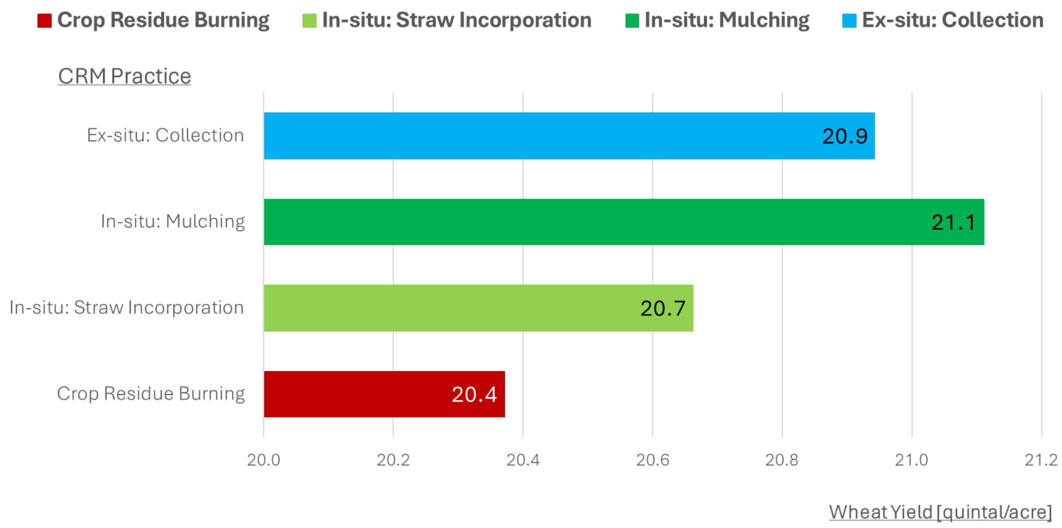
One key component of this assessment is to understand cost to farmers to undertaking different CRM methods as the field is cleared of the rice straw to sow the next crop. The cost of the conventional method, that is crop residue burning followed by extensive tillage is INR 3,212 per acre which is used as a benchmark to compare cost of alternatives practices under different scenarios- intervention group where the shared economy model for farm tools is available and standard group without intervention. The results form our assessment are plotted in Figure 9.1 and following key conclusion can be drawn from the cost assessment-

1. The cost of rice straw management via mulching is lower than the conventional crop residue management for both intervened and standard groups and much lower for intervention groups- 16% lower for than the conventional method- Crop Residue Burning (CRB). The cost of straw incorporation is in fact quite close to the cost of CRB even under the intervention. Cost of straw incorporation for standard and intervened group, is 25% and 8% higher than that of CRB, thus with support, handholding and capacity building, farmers are willing to spend this much to manage rice straw in a more sustainable manner. Overall these two broad in-situ management methods are found to be cost-effective for famers.
2. The cost of baling has drastically reduced over the course of past few years, which was initially twice than that of conventional method (CRB). It is now much more affordable to farmers- only 9% higher than CRB or convention method for the intervened group. This is a key factor leading to higher adoption of baling across intervened clusters It is worth noting that the cost of baling is still high for standard group without intervention- 39% higher than CRB.

10. Impact on Agricultural Productivity

Impact of rice straw management on overall farming productivity is understood by assessing the crop yield and farm inputs scenario for plots under different set of practices in the consecutive crop that is wheat in the rabi season. literature indicates that the in-situ management of rice straw is estimated to improve the wheat crop yield by 2-10% (Kumar et al 2015, Aryal et al 2016, NAAS 2017, Kakraliya et al 2018, Ram et al 2018 and Jat et al 2019). Yield serves as an important benchmark to evaluate performance of the intervention and results for average crop yield in plots under different practices in intervention areas are plotted in the Figure 10.1. As captured in the Figure 10.1, all newly adopted practices provide better crop yield and help farmers overcome the yield plateau due to years of burning. Mulching is able to provide farmers the highest returns in yield gain compared to all other crop residue management methods.

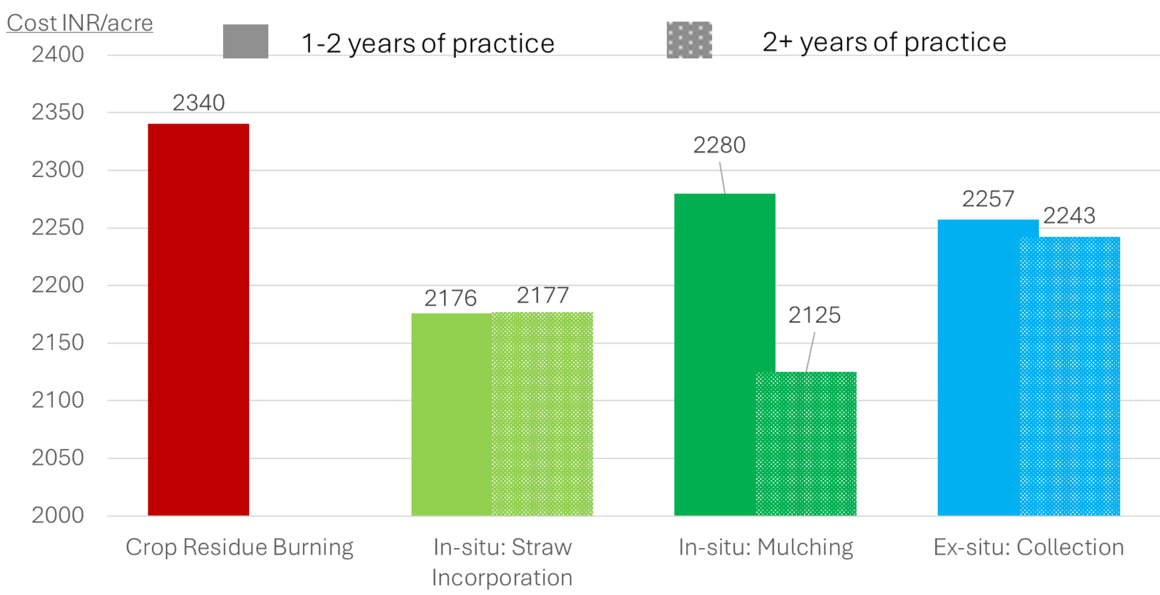
Figure 10.1 Wheat Yield in Plots under Different CRM Practices



Source: CII Cleaner Air Better Life (2024) analysis of primary data from field

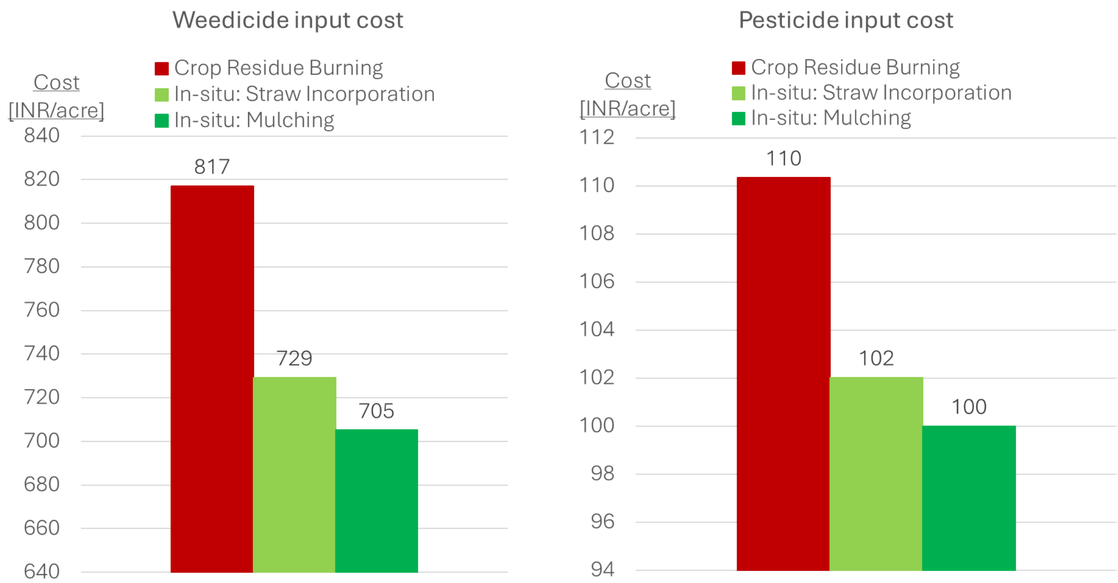
Similarly, the key results for the cost of fertilisers and chemicals (weedicides and pesticides) for different practices are summarised in Figure 10.2 and 10.3 respectively. The newly adopted alternatives require lesser chemical inputs and cost lesser to farmers (for pest and weed control) when compared to the conventional method or CRB. Also, as clear from the two figures, mulching has the clear advantage over other methods when it comes to cost of chemicals. The consumption of chemicals under mulched plots can actually be higher than other methods in the first year of adoption as it takes a year or two for farmers to realise these benefits with changing soil dynamics change after years of burning. This is perceived as a major inhibiting factor in adoption of in-situ management methods especially the mulching (FGD 2024). Finally, average farmer costs are useful to evaluate intervention, but they do not reflect the long term benefits of these alternative practices as they deals with large populations who recently shifted to new practices. It is therefore useful to consider progressive farmers' perspectives which are being captured in the next section (Section 11).

Figure 10.2 Cost of Fertiliser (Urea & DAP) Application for Different CRM Practices



Source: CII Cleaner Air Better Life (2024) analysis of primary data from field

Figure 10.3 Cost of Chemical Inputs for Different CRM Practices



Source: CII Cleaner Air Better Life (2024) analysis of primary data from field

11. Perspectives from Progressive Farmers

Mr Balwant Singh is 90-years old progressive farmer from rural block of Nabha, Patiala in Punjab. He has been incorporating rice straw in soil for 31 years. He is a pioneer who started in-situ management even before the advent of rotavator and did so with disc harrow and cage wheel for 20 years, before settling with the rotavator. His average yield is 20-25% and 15-20% higher for wheat and rice respectively, when compared to farmers in region who follow conventional practice of crop residue burning. This is quite an achievement considering that he now applies one-third lesser inorganic fertiliser and does not need to apply micro-nutrients to soil.

Mr Joginder Singh from Rania block in Sirsa has been practicing mulching rice straw in the field for nine years as of 2022. He is obtaining a consistent yield of 22-23 quintal wheat grain per acre. He is, in fact, also growing legume as intermittent crop between rice and wheat, and combined effect of this has led to 50% reduction in his usage of urea as inorganic fertiliser input. During the field preparation and sowing operations with mulcher and happy seeder respectively, Joginder also utilises the waste decomposer in his field so that the mulch layer decomposes faster.

Mr Raghuveer Singh, a progressive farmer from Rania block in Sirsa, in fact, adopted the practice of mulching (with happy seeder) 8 years back when his soil was degraded so much due to overuse of chemical inputs that his crop yield halved to 9-10 quintal wheat per acre. Mulching helped Raghuveer Singh restoring the soil health and getting the yield level back to 20-22 quintal wheat per acre. Not only this, but he also has to expend 30-40% less fertiliser and 33-67% less irrigation water. Having tried both soil incorporation and mulching, Raghuveer has become a strong advocate for the latter and educates farmers on benefits of mulching.

Mr Harwinder Singh from intervened Samrala rural block in Ludhiana has been mulching rice straw for 8 years now. He is using a ***new emerging methods of mulching which was devised by farmers themselves*** and are now gaining traction with others. It entails manual broadcasting of wheat seeds in the field with standing stubble of the previous crop (rice) and subsequently using 'mulcher' to chop standing stubble and create an even mulch layer of the rice straw. Having tried this on few acres in the beginning, Harinder Singh now follows this practice over his entire 28 acres farmland. He has been actively advising numerous other farmers to do the same. In addition to sustaining soil health and crop yield, mulching has helped him save INR 2,000 per acre in weedicides cost. The mulch layer also helps retain moisture which means that irrigation is not required for an initial 40-45 days period which is extremely relevant for the region with fast-depleting groundwater resource.

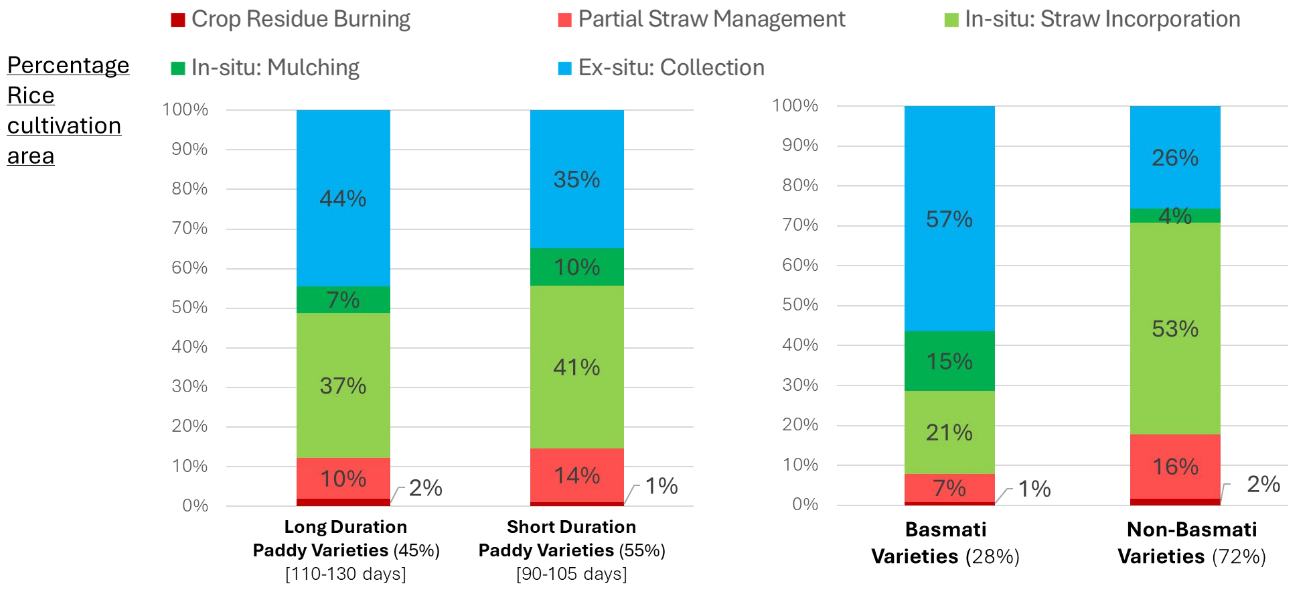
Mr Butta Singh from the rural block of Samrala in Ludhiana, Punjab has been practicing mulching with happy seeder for six years. His field is an excellent example of what mulching can achieve. As sowing the next crop after mulching (with a happy seeder in this case) does not require any tillage, the least disturbances in the topsoil and top layer of mulch almost eliminate weeds and resulting weedicide demand which is a significantly part of the overall cost of cultivation. Although he is still applying the same amount of pesticide (one standard spray per season), his weedicide demand has reduced to near zero. On top of this, his DAP and urea requirements have come down by 25% and 45% respectively as a result of nutrient recycling with the rice straw mulch.

Mr Megh Raj Singh, rural block of Barnala, Punjab, has been practising in-situ management for 8 years. The soil type in this intervened block is soft, but the soil in Mr Singh's fields is relatively harder. So after having practised mulching with a happy seeder, he finally switched to super seeder in 2022. Although he has been able to sustain his crop yield consistently through at 30 quintal rice per acre, his weedicide requirement came down to one-third due to no-tillage under the mulching regime for 7 years. Mr Megh Raj Singh is also a strong advocate of the new improved paddy variety PR-126, as he speaks ardently about the higher urea demand and higher climate vulnerability of the older variety, that is PUSA-44.

12. Key Lessons from the Field

This section summarises lessons from the field and includes new learnings which are not captured in the earlier sections focused on the evaluation of the intervention's impacts. The Figure 12.1 below shows the share of practices by- 1. crop type: basmati vis-a-vis non-basmati and 2. crop variety: short duration vis-a-vis long duration varieties of rice crop in the intervened areas. This is important background information from the CABL intervention to understand probable factors behind burning and adoption of alternatives. As clear from Figure 12.1, **crop residue burning in now prevalent in basmati crop as well in the region as opposed to the common knowledge.** Similarly is the case with the short-duration (90-105 days) crop varieties where one would typically expect an adequate time window for managing post-harvest remains of the rice crop**.** Evidently, farmers prefer to recycle the straw back into the soil for non-basmati varieties while baling is more prevalent in basmati due to higher economic and nutritional value associated with its crop residue. Also, it is worth nothing that share of mulching is almost one-third in non-basmati as compared to basmati.

Figure 12.1 **Share of Adopted Practices by Crop Varieties**



Source: CII Cleaner Air Better Life (2024) analysis of primary data from field

In addition to key environmental and socio-economic benefits quantified in this assessment, there are significant benefits to farmers in long-term from soil health gains and as a result- better ability of the cultivated crops to resist extreme climatic events which have become more rampant in the recent years. We are able to quantify one such climate resilience benefit from hard evidence from field. This is from the time In March 2022 (AY 2021-22), when heatwave severely impacted the near mature rabi crop leading to decline in overall productivity of the crop (represented here in average wheat yield across intervention areas) (Bal et al 2022). Results of our assessment of this situation in the intervened villages is provided in Figure 12.2 in both analysis of primary data from farmers as well as photographic evidence. As seen in Fig. 12.2, average yield across wheat crop declined to 17 quintal/acre in 2021-22 from 21.25 quintal /acre in previous agricultural year 2020-21 with overall decline recorded at 20%. This impact is visible in harvested grain from two different plots as shown in the top two photographs in the Figure 12.2 and **grain from mulched plot shows much better resistance to the impacts of the heatwave.** Results for wheat yield from plots under different practices in this year are also captured in the table as part of the Figure 12.2 which points to clear evidence that although all plots under different CRM practices were affected, fields under alternative CRM practices, especially mulching, provided better yields.

Figure 12.2 **Impact of Heatwave on Crop Yield**

	Wheat Yield: AY 2020-21	Percent Decline
	quintal per acre	*percentage*
Crop Residue Burning	16.2	24%
In-situ: Straw Incorporation	16.8	21%
In-situ: Mulching	17.3	19%
Ex-situ: Collection	16.9	21%

Note-
Average yield in previous AY 2019-20 at 21.24 Quintal per acre is used to understand decline in consecutive year

Source: CII Cleaner Air Better Life (2024) analysis of primary data from field

Figure 12.3

Fungus or blackening impact of heavy rain in the year 2022 on paddy yield

There are numerous other climate resilience related benefits to farmers that are not quantified in the assessment e.g. micro nutrients, grain quality, nutritional value etc. As part of this assessment, interviews of progressive farmers were undertaken to build and embed these long-term perspectives (See Section 11).

Two other key evidences that emerged from these interviews, focused group discussions at farmer cooperative level and actual field verifications are captured in next two figures- Figure 12.3 and Figure 12.4 and help further elaborating the evidence presented in figure 12.2.

Crop resilience to extreme weather is visible in harvested grains from plots under different practices as shown in the top two photographs in Figure 12.2. Wheat grain harvested from mulched (rice straw) plot shows better resistance to the heat wave. Similarly the Figure 12.3 shows the impact of heavy downpour and strong winds in 2023 where mulched plot (right photograph) shows much better resistance compared to a plot under crop residue burning (left photograph) in the same area due to better soil structure from recycled carbon. All the key lessons from the field are again summarised in the Box 12.1.

Figure 12.4

Visible impact of heavy rain & winds in the year 2023 on wheat crop

Box 12.1

Key Lessons from the Field

1

A replicable model for a sustained community-level change on the ground is possible if farmers' major needs namely- 1) capacity, 2) training, 3) tools & 4) 'round the year' farm advisory are addressed cost-effectively in participatory planning with farming communities.

2

In practice, the in-situ management method of "straw incorporation" has become the most widely adopted alternative across intervention areas and the Punjab-Haryana region in general.

3

Despite its highest productivity gains as documented in the report, "mulching" has seen a very low adoption rate in recent years. This can be attributed to misconceptions of risks among farmers, low awareness and at times, a lack of proper tool training.

4

Soil health gains & climate resilience benefits need to be studied better across the region for communicating the full cost and benefits of crop residue management to farmers. Progressive farmers, undertaking in-situ management for more than 6-7 years can be leveraged by agricultural extension services to communicate long-term benefits.

5

Multiple initiatives by Central and State Governments (Punjab & Haryana) have been successful at increasing the level of awareness and penetration of farm tools to reduce the extent of rice stubble burnings by nearly 50% by AY 2023-24 since the release of the CII-NITI Action Plan for Biomass Management in AY 2017-18.

6

The positive momentum built with the adoption of in-situ management needs to be sustained with emphasis on improving the adoption of mulching based on its cost-effectiveness for marginal-small farmers and much better resilience of mulched fields to cope with extreme climatic events which is a new norm.

7

Sustainable crop residue management practices, especially in-situ management practices, enhance farmer's productivity and reduce reliance on chemical inputs.

8

Traditional crops such as millets, maize, legumes etc. can be leveraged for crop diversification in the region due to existing know-how for their cultivation among farmers.

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The Mantosh Sondhi Centre, 23, Institutional Area, Lodi Road, New Delhi – 110 003 (India)
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