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CII Cleaner Air Better Life

CROP RESIDUE MANAGEMENT

IMPACTS AND LEARNINGS FROM THE FIELD

CII CLEANER AIR BETTER LIFE IMPACT ASSESSMENT REPORT 2020-21

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Tel: +91-11-24629994-7, Fax: +91-11-24626149; Email: info@cii.in; Web: www.cii.in

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Impacts and Learnings from Field

Mohit Sharma, Ishan Sahajpal, Nitish Sharma, Aditya Bhuyan

CII – Cleaner Air Better Life
Impact Assessment Report 2020-21

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- The Mehdoodan Multipurpose Co-Operative Society, Ludhiana
- Bharat Multipurpose e Cooperative Society, Rohtak
- Thakur Agriculture Society, Fatehabad
- Gidranwali Agriculture Society, Sirsa
- Mohamadpuria Agriculture Kisan Society, Sirsa
- Rampur Thedi Panchayat, Sirsa
- Khushaal Agri Producer Association, Ludhiana
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- Khushaal Honey and Dairy Producers Association, Ludhiana

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Summary for Decision Makers

Majority of crop residue burning in India is associated with cereal crops with rice-wheat together owning the maximum share 84% of this.

Crop residue burning rapidly intensified pan-India and grew six-seven times in past seven decades, from 18 million tonnes to 116 million tonnes between 1950-51 and 2017-18, as national food security policies focussed on increasing production of cereal crops to secure adequate national supplies. Majority of crop residue burning in India is associated with cereal crops with rice-wheat together owning the maximum share 84% of this. Mechanisation of farming and prevalence of rice-wheat monoculture in food bowl of India: Punjab and Haryana are key reasons why crop residue burning flourished in this region and became a predominant practice. Burning post-harvest remains even gained popularity as a major method to get rid any pests from previous crop in the field while field is prepared for next crop. But this scenario rapidly has changed in last few years, due to concerted efforts of multiple agencies on ground, to tackle crop residue burning.

The Central Sector Scheme launched by the Government of India (GoI) in 2018 and initiatives from multiple agencies paved way for better awareness and availability of tools in these agrarian states. Within the rural areas intervened by CII and evaluated latest in this report till agricultural year 2020-21, adoption of burning-free sustainable practices in the baseline year (before interventions evaluated in this study) was found to be much higher (ranging 23-35% across geographies) in later years compared to merely 3-5% in 2017 which is a benchmark for this study.

Today greater number farmers realise that it is desirable to curb burning from the perspective of safeguarding their families who are affected the most from health impacts of resulting air pollution. But farmers across intervened Northwest (NW) Region need practical solutions to existing challenges on ground around the availability and affordability of tools, training and advisory to change their practices.

The Crop Residue Management interventions under CII Cleaner Air Better Life (CII CABL), which are evaluated in this study, involved three years of extensive work in crop residue burning hotspots of Punjab & Haryana where rice is a dominant crop grown on 97% of the agricultural area. Recognised by UNDP SDG Action Award and Global Development Network, the CII CABL programme has created successful model for community-scale and sustained adoption (more than 80% farmers adopting burning-free methods) of sustainable agricultural practices across 7 districts of two agrarian states. Intervened farmers were provided all the know-how, technical training from PAU Scientists, farm advisory support by team of field staff and needed farm equipment at tool banks managed by the farmer groups. Farmers used multiple tool combinations on ground to tackle crop residue and these combinations are evolving with introduction of various new tools in the market which are essentially upgradation to existing tools for managing crop residue more effectively. Three major techniques including- mulching, straw incorporation and baling/collection are evaluated in this report with twelve major tool combinations or sub-methods which are classified under three board methods as adopted by farmers under this programme- 1. Mulching 2. Straw incorporation 3. Baling.

[1]among many such as- convenience, lack of know-how, availability of finances or hardware tools, declining decentralised dairy and other extant uses of straw
[2]adopted by more than 1% farmers

Two of the earlier methods constitute in-situ management practices with fundamentally change the ways in which farmers:

- Prepare field after harvesting of rice
- Sow rabi-crop which is predominantly wheat in NW India
- Apply farm inputs in all sown crops or so-called agronomy practices

The last method 'baling' or so-called ex-situ management which is simply clearing the fields in preparation for the next crop by chopping and baling the straw out of the fields, is seen risk-free and convenient method by farmers.

It is promoted and practiced to a limited extent, predominantly in areas where:

- In-situ management is not feasible due to various contextual factors primarily related to prevalent soil conditions or cropping systems
- Economic opportunities for utilisation of biomass outside agriculture e.g. Proximity to industrial boilers or straw-scarce region such as Rajasthan

Although straw incorporation has emerged as a clear winner as the most widely adopted method to tackle rice straw, mulching is documented to result into consistently higher crop yield for farmers with the highest environmental benefits for rural ecology. Various climatic factors over the years, such as humid and hot weather, have exacerbated farmer and field specific challenges with the mulching impeding its adoption rate. Field data and further investigations reveal that impact of these isolated incidents is significantly lower on overall farmer population compared to the perceived impact by farmers. Those who preferred and adopted mulching have continued with sustained adoption motivated by the results over the years.

The programme results are derived using sampled data from farmers in 172 villages intervened by CII over the three agricultural years from 2018-19 to 2020-21. Combined with the evidence and learnings from ground, programme results provide actionable framework which can be replicated across the NW region. Overall results indicate that out of total 1,57,924 acres agricultural land and 27,863 farmers intervened by CII, 85% of total farmers shifted away from complete and open burning of the crop residue from the rice crop adopting new practices on estimated 87% of the intervened farmland. Programme led to awareness and positive stories in the neighbouring areas leading to significant spill over impacts. Overall adoption of sustainable practices in 172 villages grew by +77.5% from average 51% farmland under complete burning in baseline year 2019 to average 13% in year 2020. The 70 new villages, which were intervened for the first time in 2020, observed even higher level of burning at average 77% farmland in the baseline year and as a result of field interventions- adoption of sustainable agricultural practices grew from 23% to 87% in newly adopted villages.The overall growth rate in adoption fell from 83% in 2019 to 77% in 2020. This expected due to impacts of COVID19 which caused manpower shortages for farmers across NW states.

Additionally, sixty-one new villages were intervened by CII in the latest agricultural year 2021-22 replicating the work in total 226 villages and creating model rural clusters across 10 districts in Punjab and Haryana. As shown in the Box SDM1, the CII implementation model is designed to address upfront and operational challenges faced by farmers for crop residue management and is comprised of four key set of activities to promote sustainable agricultural practices- (1) participatory planning and monitoring (2) behaviour change communication (3) shared-economy for tools (4) trainings through dedicated field volunteers. This model has evolved with experiential learning over the years, and it is worth noting that initially in piloting year in 2018, CII tried two different models- (1) Viability Gap Funding (VGF) through shared economy model and (2) Direct financial support to farmers. Essentially similar set of activities were followed under two model except the third component on 'shared economy for tools' (See Box SDM1) which was replaced by 'direct financial support' to participating farmers under the second model. This model was later discarded based on evidence from ground which indicated massive success with shared economy model (74% burning free farmland) as opposed to direct financial support model which yielded limited success (40% burning free farmland). This proves timely availability and affordability of agricultural tools, which are needed by farmers only in fifteen days in a year, are extremely important enablers on the ground.

BOX SDM 1: Overview of CII Crop Residue Management (CRM) implementation model in the North-West States

Participatory Planning with Rural communities

Continuous dialogues are held wiht farming communinties to understand their challenges and accordingly pitch solutions which are ultimately decided by the community itself

Multi-pronged Behaviour Change Communication

Multiple communication channels are deployed in villages to build awareness on importance of sustainable agriculture practices and air pollution from crop residue burning which impacts human health as well as agricultural productivity

Shared-Economy for Tools with Farmer Co-ops & FPOs

Tools needed by farming communities are procured either at the full cost or subsidised cost under the Central Subsidy Scheme (based on availability) to create shared-economy model for farm tools with the farmer groups-Farmer Co-operatives and FPOs

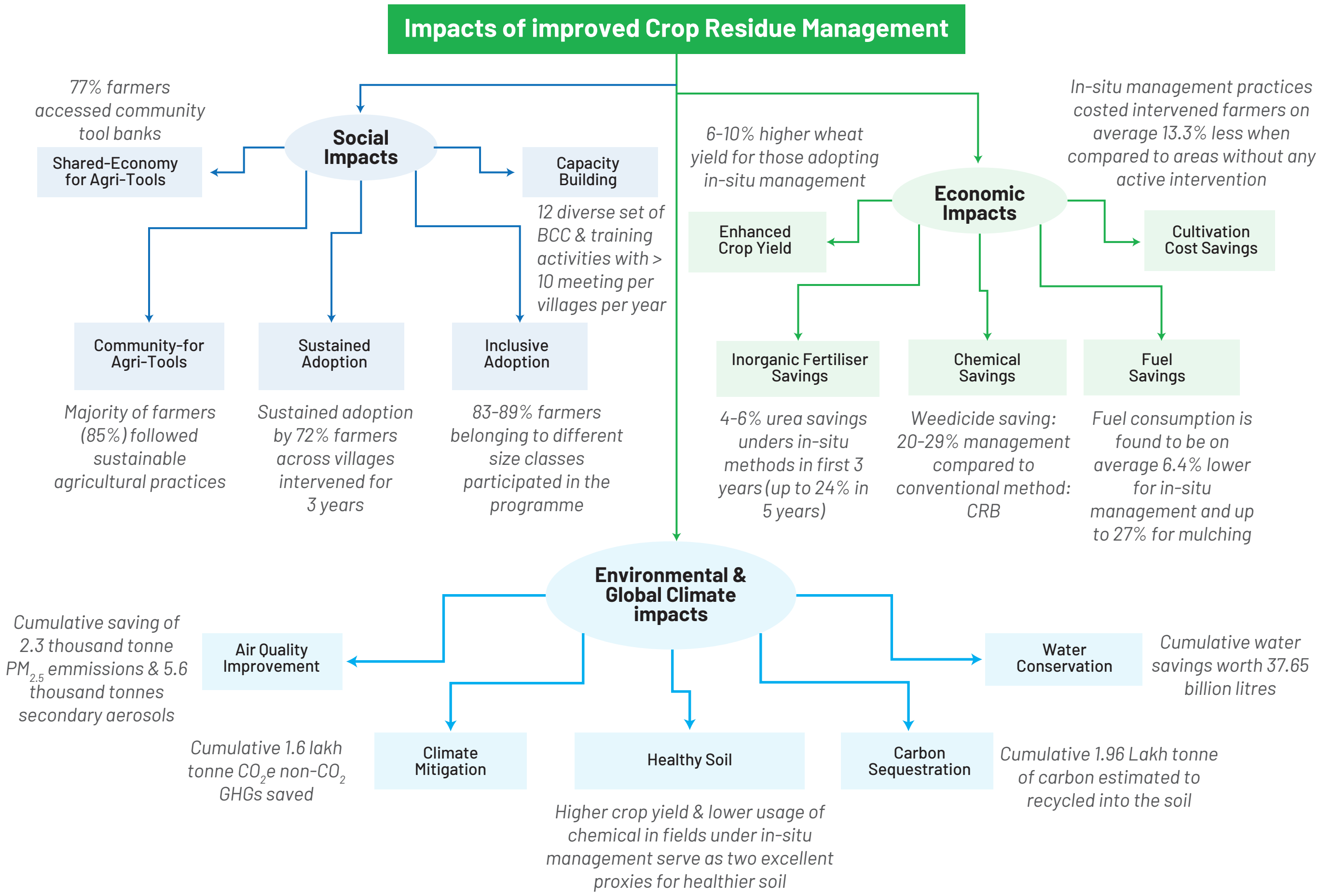
Trainings (SAU Scientists) & 24*7 Farm Advisory (Field volunteers)

Master trainers and village volunteers were trained at SAUs who then provide further technical handholding and support to farmers in their communities guiding them on new practices throughout agricultural year

Source: CII CABL (2022)

Besides local air quality gains, the second and perhaps most important perspective which is really gaining momentum with farmers for curbing stubble burning is 'healthy soil'. It is fundamental to- (1) sustained productivity from agriculture in the long-run due to better soil dynamics and higher soil-biodiversity, (2) climate resilience of crops or plants in wake of extreme climatic conditions such as- heavy rainstorms, droughts, heat waves etc. which is the new normal in the NW region due to climate change. Healthy soil can also act as an effective terrestrial sink for the organic carbon which is otherwise released into the atmosphere in the form of air pollution and greenhouse gas emissions. Capturing productivity and other economic gains made by farmers due to adoption of environment-friendly practices is major effort undertaken in this study. This study also attempts a framework to evaluate any crop residue management programme with farmers along the social, economic, and environmental dimensions of sustainability. All evaluated impacts from CII programme, through major data collection drives with farmers, are summarised and captured in the Figure SDM1.

Figure SDM 1. Summary of key impacts evaluated in CII Study across three years



Source: CII Cleaner Air Better Life (2022) Analysis

Key Learning from Three Years of CII CRM Work with Farmers:

Availability and Affordability of Agriculture tools

Availability and affordability of hardware tools which are needed by farmers only in fifteen days in a year, are extremely important enablers on the ground. Farmers groups including Farmer Cooperative Societies (FSCs) and Farmer Producer Operations (FPOs) can be leveraged to fill the existing gap on ground and provide these services to farmers on shared basis. Role of these farmer groups is especially crucial as they often provide short-term credit linkages to small-medium farmers for key agricultural activities throughout the year.

Technology Diversification versus Informed Choices by Farmers

One size does not fit all but multiple available options without proper information on their merits and associated risks leads farmer less decisive. Therefore, local-level participatory planning with rural communities while considering of specific contextual factors such as crops, varieties, soil types etc. plays a crucial role in planning shared-infrastructure which suits the local needs. 12 major tool combinations which are adopted by farmers as documented in this study, are influenced by numerous factors. Generally, farmers pick options with least fuel consumption until other option is convenient and less time consuming.

There are multiple new tools under development and few of them were also recently introduced in market for farmer utilisation. Developments or upgradation with happyseeder are required to promote mulching. Upgraded version of HS which is Smart seeder was recently introduced and underwent trails in 2021-22. Its performance and farmers' feedback need to be better gauzed in coming year as positive development with smart seeder may truly unlock potential of

mulching and zero tillage method with most environmental merits for the NW region. Considering there will be multiple tool combinations, more than dozen, adopted by the farmers, farmers will need detailed know-how for their field application of the new tools introduced. Agriculture universities with their extension services need to work with tool manufacturers to produce package of practice for effective utilisation of these tools and prepare advisory for farmers on tool combinations best suited for specific field conditions e.g. soil type and agro-climate zone, enabling farmers choose the most cost-effective option.

Technological Challenges in In-situ Management

Government of India through its agriculture mechanisation mission have led to significant improvement in penetration of in-situ tools. Still, there is room for improvement as number of tools are under-utilised and with introduction of new high-capacity tools, the demand for high power tractor has also increased. With promotion of in-situ tools government need to promote shared economy model for agriculture tools in the NW states, enabling farmers utilise different tools on rent as per their preferences and prevalent field conditions. Penetration of other needed and less prevalent tools can be prioritised basis such information derived from farmer surveys.

In-situ management tools were accessed by majority of farmers (77% of all farmers) though shared-economy model created by CII with farmer groups (FSCs and FPOs) and these include - Mulcher at 94%, MB Plough 98%, Superseeder 73% and Happyseeder (HS) at 58%. The penetration of HS has significantly improved due to GoI subsidy scheme and surveyed data shows that 26% farmers used self-owned HSs.

Superseeder, a tool for enabling straw incorporation and sowing next crop, has emerged as the most preferred tool for in-situ management in 2020-21. While superseeder with superior straw mixing capability, which address the 100% in-situ management challenge with other tools, is fast replacing the use of rotavator in in-situ management method: straw incorporation, it requires high horsepower (greater than 55HP) tractor which is a limiting factor for most marginal-small farmers. Although high horsepower tractors were rented by CII Foundation to support farmers, it remains key concern as numbers of such tractors are limited in States. Partial straw management, which is a hybrid practice of burning 30-40% of heaped crop residue and incorporation remaining into the soil, continued at significant pace in last 2-3 years due to technical challenges with most tools and specific field conditions hinder utilisation of 100% rice straw in in-situ application. This has come down substantially in 2020-21 from 34-35% to 4-9% across different landholding size classes of farmers due to due to large-scale adoptions of superseeder in 2020-21.

Farmer adoption also improved, marginally, in favour of less fuel and time-consuming practice of mulching. There are underlying concerns based on past experiences and perception which hinder most fruitful

The penetration of HS has significantly improved due to GoI subsidy scheme and surveyed data shows that 26% farmers used self-owned HSs.

decision making. Despite farmer apprehension to adopt happyseeder in new areas, those who have adopted mulching and continue to use happyseeder are deriving more yield benefits on average from mulching at 7% higher yield on average compared to conventional practice involving crop residue burning. In addition, there are significantly higher environmental merits associated with mulching as documented by this study. Mulching provides the highest yield to farmers with up to 10% higher yield recorded after 3 years. Straw incorporation showed comparable yield benefit at 6% in 2020-21 but mulching yields much better results over straw incorporation with consistent increase in yield with sustained adoption.

At this critical conjecture of technology adoption in the region, it is important that diverse technology options are available to farmers with clear information on costs, benefits, and associated risks. There is a clear need of dedicated information campaigns based on field data to rectify farmers perceptions around mulching.

Long Term Solution- Crop Diversification

Crop residue burning has led to such severe levels of air quality due to concentrated burning incidents across states happening along only 1-2 weeks, one of the major reason been the widespread adoption of long duration Pusa varieties of paddy which allows very small window to manage residual straw. Farmers in the region need to move away from these Pusa varieties which not only lead to burning but is also draining out water, decreasing water table leading to future where in two or three decades, groundwater for drinking might not be available. On the long-term considering the huge irrigation demand, crops other than paddy need to be explored in the region with effective market linkages built to allow farmers switch to alternate crops suitable for the region.

Meanwhile, the paddy variety also impact the farmers overall choice of practice. In our intervened clusters of Barnala, Patiala, Sangrur almost 73-88% farmers adopt Pusa-44 paddy variety along with almost 54% farmers in Ludhiana. Even in Sirsa and Fatehabad long-duration paddy variety PB-1401 is adopted by majority of farmers (66% in Sirsa and 48% in Fatehabad) leading to the need of baling in these clusters. Significant number of farmers in Haryana (Fatehabad and Rohtak) who opted for shorter duration varieties of rice PB-1509 are found to be more likely to move towards sustainable practices as straw management becomes easier due to comparatively smaller amount of post-harvest crop residue. However, even in these cases, proper awareness and capacity building is required to move away for conventional practices.

Farmer Communication and Handholding

As documented in the report the peer-to-peer learning and augmentation of extension services in rural areas is the best way forward for raising farmers capacity and confidence on improved crop residue management techniques. Majority of farmers, 90% of the surveyed farmers, believe their fellow farmers or peers with almost half of the farmers believing Scientists at State Agriculture Universities (SAUs) as well as Krishi Vigyan Kendras (KVKs). Significantly smaller number of Farmers trust any other agency or entity.

CII CRM programme executed 12 diverse set of behaviour change and communication as well as training activities with support from State Agriculture Universities and Local Agriculture Departments in intervened areas with estimated 10 meeting per villages per year involving all sections of local communities. Local leaders, local agriculture officials, farmer groups and progressive farmers were crucial to build trust with local communities.

Chemical Saving with Adoption of Sustainable Agriculture

Diverse economic benefits derived by participating farmer especially those who adopted in-situ management are described in detail in this report and form a strong basis for continued awareness and information to farmers across NW region.

In-situ recycle of paddy residue leads to recycling of incorporated nutrients like Nitrogen, Phosphorus, Potassium and Carbon along with other micro-nutrients like sulphur and manganese. Biomass decomposition boosts the biological activities of the soil and rejuvenates the soil capacity to recycle and recover nutrients along with improving retention capacity, leading to improvement of soil quality over the period. All this comes under the broader head of nutrient management. Nutrient Management is the way of keeping soil healthy and fertile, this technique helps in balancing various nutrients in the soil leading to enhancing soil fertility.There is a need to develop an appropriate soil nutrient and cropping system, that minimises the need for chemical fertilisers. Monoculture of rice-wheat cropping pattern prevalent in the NW region has resulted in increased vulnerability to pest and disease attacks. Recycle of nutrient will enable soil to overtake these pests and weed attack. Chemical input in the field for weed and pest management is generally used in excess and pre-emptively, this is mainly derived by farmer perception and peer farmers' practices, this gap needs to be filled with continuous handholding support to farmers through extension services.

In our study we realised in-situ management resulted in lower fertiliser consumption at 4-6% in last three years whereas the fertiliser consumption went up for farmers continued with burning at 8-12%. Based on progressive farmers data this reduction is expected to come down by 24% in 5 years of adoption. However, it is worth noting that in the first year of adopting in-situ methods, fertiliser consumption may go slightly by 3-5% owing to nitrogen immobilisation and hence there is a strong need to communicate these risks to farmers adopting in-situ for the first time. Application of higher amounts (5% higher urea consumptions for baled fields) of inorganic inputs correlates with commensurate nutrients in the biomass baled-out of the field.

Direct savings for weedicides are quantified to be -29% and -20% for mulching and soil incorporation respectively (compared to baseline/CRB which is INR 686 per acre). Besides higher benefits, mulching also shows consistent decline in weedicide consumption or cost from -20% for first year of adoption to -45% in three years. Introduction of Integrated Pest Management (IPM) along with in-situ management will lead more benefits to the soil and surrounding environment. IMP combines the use of biological, cultural and chemical practices to control diseases, insects and pests in crops. It seeks to use combined methods (physical, chemical, biological) to minimise economic, social and environmental risks and damages. IPM does not discourage spraying chemicals; but is a means to use them efficiently/selectively and only when the crop needs it. This would help in usage of less pesticide leading to the growth of a healthy crop with the least possible disruption to crop and environment.

Cultivation Cost Saving for Farmers

Fuel consumption is found to be on average 6.4% lower for in-situ management and up to 27% lower for mulching. Overall, the fuel savings have come down from 23% in 2019 assessment of 102 villages to 6.4% in 2020 due to higher adoption of new tool superseeder which is more energy intensive compared to all other tools e.g. diesel consumption for superseeder is 14.26 litre/acre as compared to 7.25 litre/acre for happyseeder or 8.1 litre/acre for rotavator.

It is found from surveyed data that tariffs charged by farmers groups, which were supported by CII, are 10-20% lower across agricultural tools compared to private service providers. Detailed modelling for cost of cultivation undertaken in this study shows that in-situ management practices costed intervened farmers on average 13.3% less when compared to other areas without any active intervention. The same cost figure is found to be much higher for areas without interventions in NW region, where in-situ management instead costs 13-26% more than conventional practice: CRB. This clearly shows the impact of shared-economy model created by CII in intervened areas. Another major finding on this front is regarding baling which is still not cost-effective (costing twice the cost of conventional method: CRB) for participating farmers due to higher upfront cost and recurring cost involved in operations and maintenance. Baling is also energy intensive and as a result, baling cost have been significantly affected, 17% higher from 2019, due to increase in fuel prices.

The data from ground from farmers adopting in-situ practices from past three years does not support popular farmer perception of huge cost involved and loss of subsequent crop. Thus, targeted awareness is needed to communicate the risks and benefits of different methods to farmers. Finally, the farm inputs scenario, which is rapidly evolving with adoption of new practices, is also driven by farmers' perceptions to a significant level. This demands better understanding life cycle costs of CRB vis-a-vis improved CRM practices and communicating these to farmers to ensure long-term sustainability of improved CRM practices.

Ex-situ Solutions to Address Gaps in In-situ Technology

There is need to boost solutions to farmers who cannot utilise rice straw in-situ i.e. farmers with alternate crop rotation (e.g. rice-vegetable-sunflower as opposed to predominant rice-wheat farmers). These farmers do not find in-situ management either cost-effective or productive for the next crop. Therefore, ex-situ as an important part of overall biomass management ecosystem, needs to be made more cost-effective or affordable to farmers. While these farmers find it easier to burn in absence of any cost-effective alternate, often they are also proactive in clearing the fields manually if they are able to find value in crop residue through use in composting, animal fodder etc. Multiple solutions therefore need to be explored and deployed for meetings the needs of all farmers in future.

CII is also piloting actionable ex-situ solutions in villages by working alongside SAUs and eco-entrepreneurs. Such solutions for ex-situ utilisation of paddy straw include- community-scale above-ground biogas plants, pit-composting and portable biochar reactor which are successfully being tried at small scale to motivate farmers and generate additional income and livelihood opportunities in rural areas. Sharing of risks and specific business expertise for aligning logistics through biomass aggregator model, which is described in detail along with eight other actionable business cases are described in detail in the CII CABL Technology assessment report on ex-situ solutions 2021, remains key to scale ex-situ uses of biomass.

But partly the reason for lack of proliferation of rice straw based ex-situ technologies in Punjab and Haryana has been relatively lower market maturity level of actionable technologies for rice straw in the region compared to other biomass types say mustard, sugarcane, wheat, cotton etc. Energy conversions, especially second-generation biofuel technologies, face the inherent challenges due to high silica and lignocellulosic content. Therefore, these identified technologies which are proven on ground need to be supported by Government and Private sector on priority basis. It is expected that such clean and green solutions will also create livelihood opportunities in rural area which will also be helpful for taking excessive environmental pressures off and mitigating air pollution in already polluted urban centres.

1. Introduction

Cleaner Air Better Life's Crop Residue Management(CRM) Programme started with the pilot intervention in 19 villages (in the districts of Patiala and Ludhiana in Punjab) in the year 2018 following the release of CII-NITI Action Plan for Biomass Management. The CRM program has so far grown from 19 villages in 2018-19 to 105 villages in 2019-20[3] to 172 villages in 2020-21. Haryana also became a part of CRM Programme in 2019 and new areas of Barnala, Sirsa, Fatehabad and Rohtak districts were intervened in this year in addition to expansions to villages in the previously intervened areas of Patiala and Ludhiana districts. Due to COVID-19 pandemic in 2020, scaling of CRM programme was limited to mainly lateral expansions (except in Samrala, Ludhiana) across the villages in previously intervened areas.This can be seen in the Figure 1 where intervened villages under the project are mapped and coloured as per the year of intervention.

This study assesses the impact of CRM interventions till agriculture year 2020-21 across 172 villages of Punjab and Haryana. Total intervened area in these geographies is equivalent to 1,57,924 acre or 63,936.84 hectare of agricultural land covering 27,863 farmers. These are predominantly the rice producing belts of Punjab and Haryana where 97% of the agricultural area is under rice cultivation. Closely following this is the wheat crop,grown on 95% of the agricultural area, mostly in combination with rice in an agricultural year. Alternate crops grown within existing two-to-three cropping system which is predominantly rice-wheat, are rather limited to 3-5%of total agricultural area and include- potato, sugarcane, sunflower, carrots, green gram, peas, mustard etc.

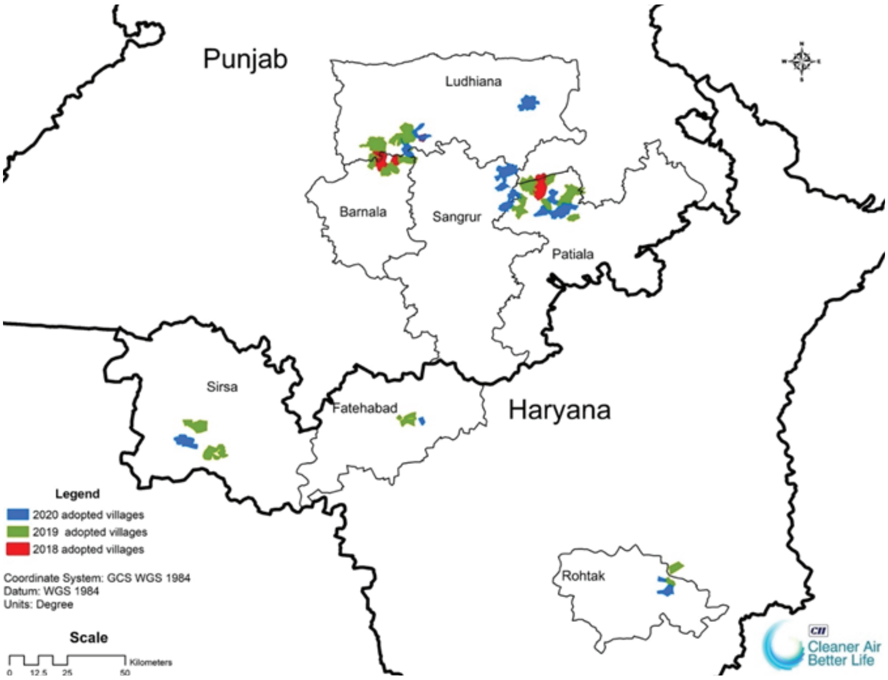
Overall adoption of sustainable practices across 172 villages improved from 51% farmland under complete burning in baseline year 2019 to 13% in year 2020. Overall, adoption sustainable practice has grown by 77.5% in 2020.In terms of agricultural area and farmers, sustainable agricultural practices were adopted on 87% farming area and by 85% farmers, limiting the conventional method of complete and open burning of rice straw to 13% of area and 15% of farmers in the year 2020. Details of the agricultural area covered in seven model clusters of villages across seven intervened districts of Punjab and Haryana are listed in Table 1.

In the 70 new villages which were intervened for the first time in 2020-21, the baseline survey indicated that 77% of the total generated rice straw was being burnt in previous year, that is 2019. As a result of field interventions, overall burning came down to 13% of total rice straw produced in these areas. Programme interventions in these new areas resulted in steep increase from 23% to 87% in the adoption of Improved Crop Residue Management Practices from 2019-20 to 2020-21.

In terms of agricultural area and farmers, sustainable agricultural practices were adopted on 87% farming area and by 85% farmers, limiting the conventional method of complete and open burning of rice straw to 13% of area and 15% of farmers in the year 2020.

[3]102 out of 105 village were part of annual assessment in 2019-20

Figure 1: Map of CII Intervened geographies in three years till 2020-21



Source: CII Cleaner Air Better Life (2022) analysis

Table 1: Details of CII Intervened Geographies in three years till 2020-21

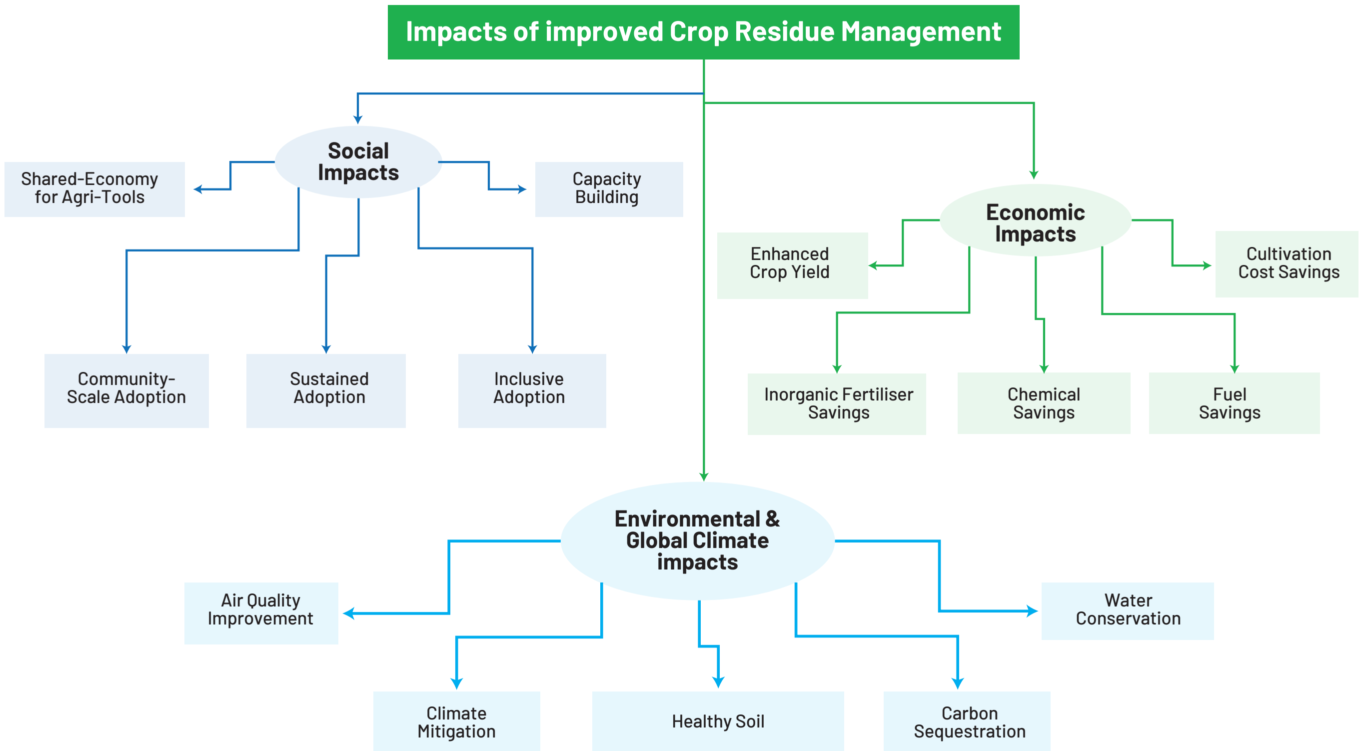
State	District or Cluster	Newly intervened villages in 2020	Intervened villages in 2019	Intervened villages in 2018	Intervened farmers by 2020	Intervened Farmland by 2020
Punjab	1. Patiala	17	47	9	10,226	52,657
	2. Ludhiana	22	22	7	5,061	50,234
	3. Barnala	0	3	0	400	5,200
	4. Sangrur	21	0	0	4,501	21,133
Haryana	5. Sirsa	5	8	0	2,440	13,220
	6. Fatehabad	1	4	0	1,200	5,380
	7. Rohtak	4	2	0	4,035	10,100
				Overall	**27,863**	**1,57,924**

Source: CII Foundation

Significant number of farmers, 68% of all farmers, practiced straw incorporation or mixing in 2020 to manage the paddy straw in the field. Newly introduced in-situ management tool named 'superseeder', which is an improved version of rotavator, provides enhanced capabilities to incorporate straw into the soil. Demand for superseeder is found to risen in this season. Hot-humid weather conditions during wheat germination in 2019 gave rise to pest infestations under mulch layer in few instances but overall impact on yield was insignificant as documented in our annual assessment in 2019-20 (Sharma et al 2019). Demand for superseeder has risen at the rate of farmers' misconception of risks associated with mulching. Total 42% of all farmers incorporating straw in the field utilised superseeder and field data shows that 73% farmers accessed it via shared-economy model created with farmer groups.

This study quantifies impacts of CII Cleaner Air Better Life's CRM programme across three dimensions of sustainability – social, economic, and environmental impacts and provides a practical framework for evaluating these impacts based on primary data from field as shown in the Figure 2. The social impacts capture the shift in agricultural practices in last three years of field intervention. Further, it is assessed whether this shift is inclusive and leads to capacity building and a permanent change at community scale. Economic impacts of CRM programme are evaluated by understanding the change in overall inputs cost and changes in crop productivity as a result of newly adopted practices for crop residue management. The environmental impacts from adoption of new practices by farmers, which are quantified across 172 intervened villages, are wide-ranging and lead to benefits across all sub-system of natural ecosystem, that is air, water and soil subsystems.

Figure 2: Overview of different impacts of improved crop residue management practices measured and described in this report



Source: CII Cleaner Air Better Life (2022) analysis

Total 42% of all farmers in corporating straw in the field utilised super-seeder and field data shows that 73% farmers accessed it via shared-economy model created with farmer groups.

2. Background

CRM programme is designed to provide a scalable delivery model for cost-effective solutions to rural communities affected by CRB.

Agricultural crop residue burning has emerged as an important challenge in the agricultural production system on account of rising air pollution episodes, short-lived climate pollutants and declining soil health. The total annual crop residue burned increased from 18 million tonnes to 116 million tonnes between 1950–51 and 2017–18 across India (GOI 2019). Crop Residue Burning (CRB) in food bowl of India still remains a major challenge for peak air pollution across Indo-Gangetic Plains. It is estimated that if existing practices continue in the same manner, accompanying emissions from CRM will increase by 45% by 2050 (Singh et al 2020).

In 2018, CII partnered with NITI Aayog for the 'Cleaner Air Better Life' initiative to develop consensus on actionable steps to address scientifically identified sources of air pollution in Delhi National Capital Region (NCR). Four action plans including Action Plan for Biomass Management were accordingly prepared by Cleaner Air Better Life by consulting diverse stakeholders across NCR airshed. Action Plan for Biomass Management was prepared by the Task Force on Biomass Management anchored at the Ministry of Environment Forest and Climate Change (MoEFCC), Government of India (GoI). Actionable steps were identified by task force by consulting Punjab Agriculture university (PAU), farmers communities and other relevant stakeholders which are documented in the (CII-NITI 2018) report. Scaling up in-situ technologies using shared-economy model was identified as the immediate actionable step by CII-NITI Aayog Action Plan released in February 2018 (CII-NITI 2018). Taking note of this, GoI launched Central Sector Scheme as part of the Union Budget 2018-19, revised in 2020, to support farmers in adopting these technologies in affected states of Punjab, Haryana and Western Uttar Pradesh.

In the same year, that is 2018, CII initiated the pilot programme on Crop Residue Management in 19 villages of Ludhiana and Patiala districts (Punjab State) to demonstrate these options at scale. CRM programme is designed to provide a scalable delivery model for cost-effective solutions to rural communities affected by CRB. CII implementation model follows an end-to-end approach consisting of following key components-

- **Multi-pronged behaviour change communication:** Continuous dialogues are held with farming communities through multiple communication channels to build awareness on sustainable agriculture practices and air pollution from CRB with its impacts on human health as well as agricultural productivity.

- **Financial support to farming communities:** Tools needed by farming communities are procured either at the full cost or subsidised cost under the Central Subsidy Scheme (depending on their availability) to create shared-economy model for farm tools with the farmer groups.

- **Capacity building of farmers for improved crop residue management:** Farm level demonstrations and trainings were conducted in partnership with State Agriculture Universities (SAUs) and State Departments of Agriculture (Punjab & Haryana). Master trainers and village volunteers were trained at SAUs to provide further technical handholding and support to farmers.

- **Participatory monitoring of stubble burning at village level:** Communities take charge of their emission by monitoring burning incidents in villages and undertaking immediate remedial measures. Field workers and local NGOs are engaged by CII field coordinators who work very closely with local-level Nigrani Committees for monitoring and controlling burning by providing timely solutions.

- **Piloting actionable solutions in villages:** CII is working alongside SAUs and entrepreneurs developing solution on ex-situ utilisation of paddy straw, demonstrate some key actionable solutions at village level to motivate farmers.

In the piloting year in 2018, to discover best suited model to address crop residue burning two different approaches were tested-

I. Viability Gap Funding (VGF) on needed farm tools to farmer groups for undertaking sustainable agricultural practices at the community-level based on a shared economy model

II. Direct financial incentive to farmers to fund the extra cost of straw management

The first model (VGF through shared economy for tools) was highly successful in demonstrating actionable solutions with farming communities (Sharma et al 2019). Within this model, 74% area was made free of burning in 2018 as opposed to 97% area under burning in 2017 (Sharma et al 2019). In comparison, we witnessed limited success in second model (direct financial support to farmers) where only 40% of farmland was managed by sustainable practices. Hence, the first model was pursued further for expansion. Key reason for this being- famers needed in-situ management tools for limited period 15-20 days and shared economy for these tools made a viable and cost-effective proposition to farmers.

Later in 2019, the programme was scaled to 105 villages of Punjab and Haryana. Total intervened area of 102 out of 105 assessed villages was equivalent to 97,531 acres or 39,469.4 hectares covering more than 20,855 farmers. In this year, we witnessed steep increase in adoption of improved crop residue management by 83% from 2018 to 2019. Overall burning came down to 24% of the total rice straw generated in these areas. In the following year in 2020 programme expanded to 172 villages covering 1,57,924 acres or 63909.57 hectare covering 27,863 farmers. This report presents the assessment of the latest field data till 2020-21 which indicates overall 81% increase in adoption of straw incorporation and 62% increase in mulching from 2019 to 2020. As a result, extent of crop residue burning in these areas came down to 13% of the total intervened farmland.

CII worked with multiple partners (See table 2) across intervened clusters including Farmer Co-operative Societies and Farmer Producers Organisation which become the supporting arm of CII to provide farmers the necessary tools and handholding on the ground. To make the community tool bank sustainable, a nominal rent is charged for tool utilisation which is used for maintenance and upkeep of machines. Farmer Co-operatives are also part of States' initiative to provide farmers short-term monitory loans and some of them also work as local tool bank for providing tools to farmers of all size classes on subsidised rents. CII collaborated with them to bridge the gap between available and required tools for in-situ straw management. Only in specific instances where in-situ did not work due to specific contextual factors, farmers were provided option of baling out the straw for use in activities outside field.

CII's field initiative encouraged large-scale behaviour change among farmers to shift from conventional practice of crop residue burning to managing the residual straw in an environment friendly manner. Out of all the methods used for residue management, straw incorporation is found to be the most preferred option among famers in 2020.

Table 2: Details of field partners across clusters in 2020

State	Districts	Partners
Punjab	Patiala	23 Farmer Co-operative Societies
	Sangrur	7 Farmer Co-operative Societies
	Ludhiana	3 Farmer Producer Organisations (Raikot) & 4 Farmer Co-operative Societies (Samrala)
	Barnala	1 Farmer Producer Organisation
Haryana	Sirsa	3 Farmer Co-operatives
	Fatehabad	1 Farmer Co-operative
	Rohtak	1 Farmer Co-operative

Source: CII Foundation

3. Methodology

The survey is also used as a tool to collect farmers' feedback to improve crop residue management programme and capture learning which are later validated with Focused Group Discussions (FGDs) with farmers.

Assessment of CII's CRM programme is based on a combination of four key data collection steps as captured in Figure 3. Customised digital data collection platform was designed to collect the farming data in 172 villages with geo-tagged information. Data was collected by dedicated team of field volunteers trained in digital data collection using mobile application. With the advent of Covid-19 in India, remote data collection method (telephonic survey) was deployed keeping in mind the safety of field staff as well as local communities. 2160 farmers or farming households were surveyed telephonically by field volunteers to collect data on farming practices with an overall objective to understand evolution of different crop residue management practices. The survey is also used as a tool to collect farmers' feedback to improve crop residue management programme and capture learning which are later validated with Focused Group Discussions (FGDs) with farmers.

Stratified random sampling of farmers was undertaken across 172 village to cover-

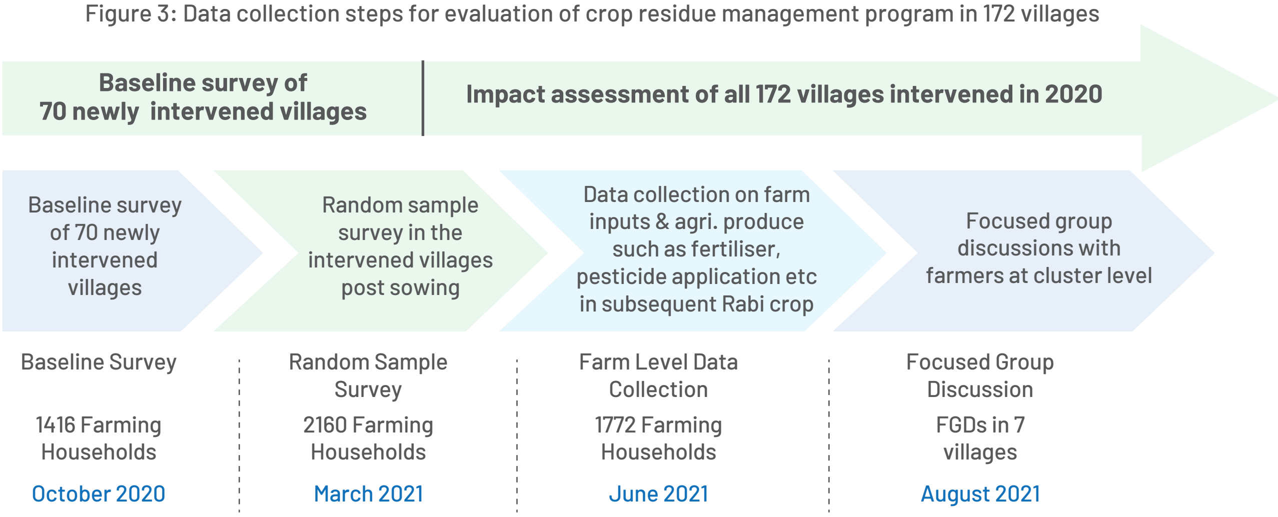
1. **Intervened farmers** adopting different practices whether convention or alternate as randomly as possible

2. **Stratified samples** so that all farmers belonging to different strata or size classes are covered in each village.

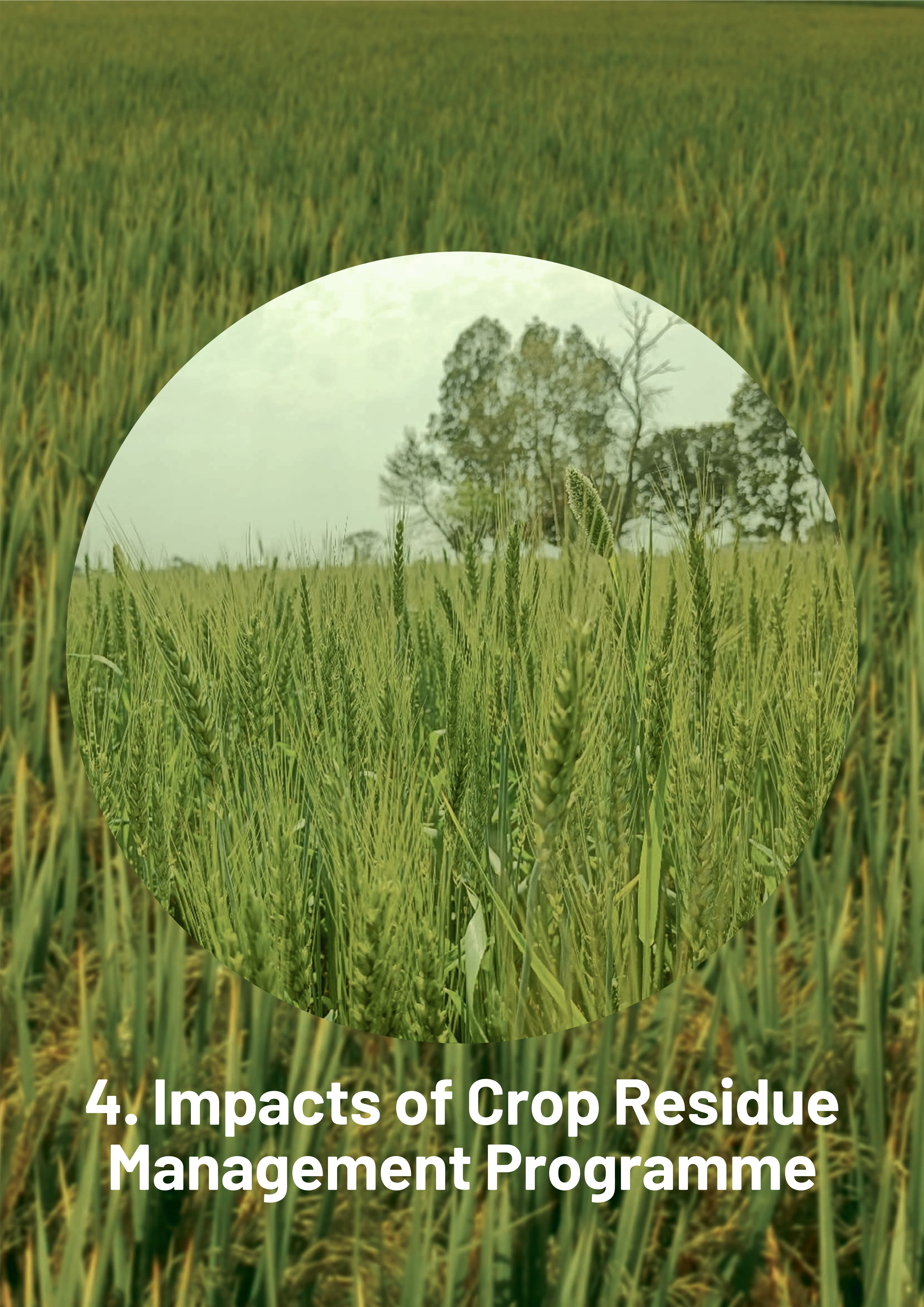
Sampling is done in a manner to keep the overall confidence interval or margin of error below 5%. Depending on the size of villages, 20-25 samples per village are collected in 172 intervened villages. The sample sizes across intervened clusters and their stratification across farmer size classes is being shown in Annex 1. Further data on full cropping cycle, ending in June 2021, was collected from 82% or 1772 of these surveyed farmers.

Community-based approach is followed to cover different farming communities and socio-economic strata in villages. This means that field team, with good understanding of local rural community and involvement in the cluster connected with farmers for balanced inputs. Stratification of samples was undertaken to proportionate number of farmers responding from each stratum (See Annexure 1). Impact information collected telephonically had underlying biases, especially due to lack of ability of volunteers to elicit farmers' confidence over telephone. These biases led to skewed data indicating lower extent of burning as compared to actual situation on ground. These biased were eliminated with the help of programme data and direct validations provided by farmer groups at in-person Focused Group Discussions in villages.

Figure 3: Data collection steps for evaluation of crop residue management program in 172 villages



Source: CII Cleaner Air Better Life (2022) analysis



4. Impacts of Crop Residue Management Programme

4.1 Social Impacts

Social impacts measure the shift in intervened areas agricultural practices which are core to behaviour change among farmers in affected areas and action on crop residue management. The framework includes measuring following impacts-

- Shared-Economy for Agri-Tools
- Community-Scale Adoption of Burning-free Practices
- Inclusive Adoption of New Practice
- Sustained Adoption of New Practices
- Capacity Building for Clean Air & Healthy Soil

4.1.1 Shared Economy for Agri-Tools

One of the key objectives of CRM programme is to create shared-economy model in rural communities to address fundamental challenge of affordability for crop residue management as these tools are needed by farmers for only few hours to few days in the entire year. Under shared-economy model, farmer groups are given the responsibility of upkeeping tools provided under the programme as per the assessed needs at the village-level. Farmer groups register farmers requests and ensure that all farmers in the village have access to these machines in timely manner and at nominal rents. Role of farmer groups, especially FSCs, is crucial for agriculture in the region and these groups often provide short-term credit linkages to farmers for key agricultural activities throughout the year.

The Figure 4 depicts the situation of farmers' access to various tools being used across rural geographies for improved crop residue management practices in intervention year of 2019 and 2020. The green coloured bars in Figure 4 indicates the share of farmers accessing shared-economy model created by CII with support from farmers groups. While these tools are used in various possible combinations by farmers, some of these also get utilised under conventional practices i.e. rotavator and Zero-Till Drill (ZTD). Majority of farmers own ZTD and as it is clear from primary data in Figure 4, this tool enjoy better penetration and is rarely accessed through farmers groups. Tools used to sustainably manage straw (Mulcher, Cutter-cum- spreader, Reversible Mould Board Plough, Happyseeder, Rotavator with Seed Drill and Superseeder) are shared by farmers through shared-economy model. Balers are usually provided by machine aggregators, service providers or private agencies. In 2019, few balers were also provided to farming communities on need basis. Key conclusions can be drawn from Figure 4 in this respect are-

- Penetration of in-situ management tools, which are exclusively used for in-situ management, is evidently still low among farmers for reasons explained in the beginning of this section. Few farmers and only medium-large farmers can afford to own these tools.
- In-situ management is promoted with farmers under CRM programme due to their huge environmental as well as soil health benefits. It is quite evident from farmer data that In-situ management tools were accessed by farmers the most though shared-economy model- on average 77% farmers utilised community tool banks created by CII with farmer groups (FSCs and FPOs) - Mulcher at 94%, MB Plough 98%, Superseeder 73% and happyseeder at 58%.
- Penetration of Happy Seeders (HSs) has improved with subsidy support from the Government- about 26% farmers used self-owned HSs. Happyseeder is key tool used for mulching and it can be used as a standalone or in combination with other tools depending on farmers preferences and field conditions. Despite, significant time and fuel savings over other methods, relatively low adoption of happyseeder is seen due to multiple factors leading to confusion among farmers which affected their perception and technology choices. But focussed group discussions with farmers and analysis of primary data shows us that there is still demand for happyseeder, being a viable option for straw management along with its high potential to curb prevalent weeds in the Rabi crop.
- A small contribution of private agencies in this category (i.e. happyseeder and superseeder) of tools is not necessarily due to involvement of external private parties. There are a small group of farmers in a village with private ownership of these tools, who rent these out to other farmers in same or nearby communities and villages.

Figure 4: A. Source of tool preferred by farmers (2019)

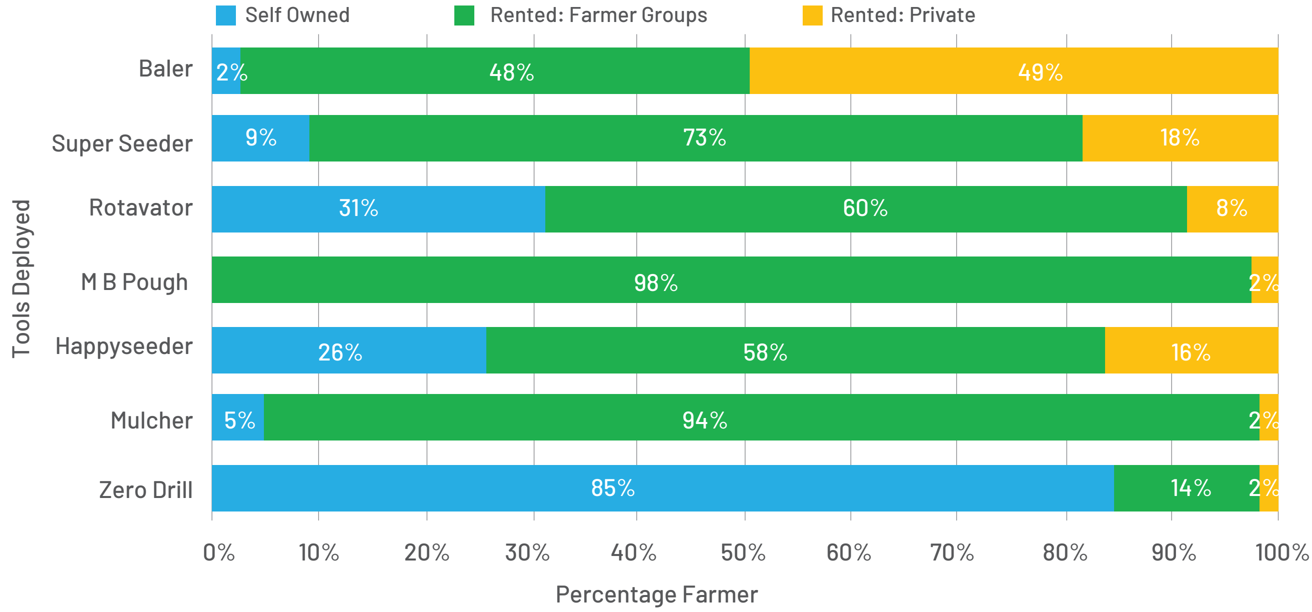
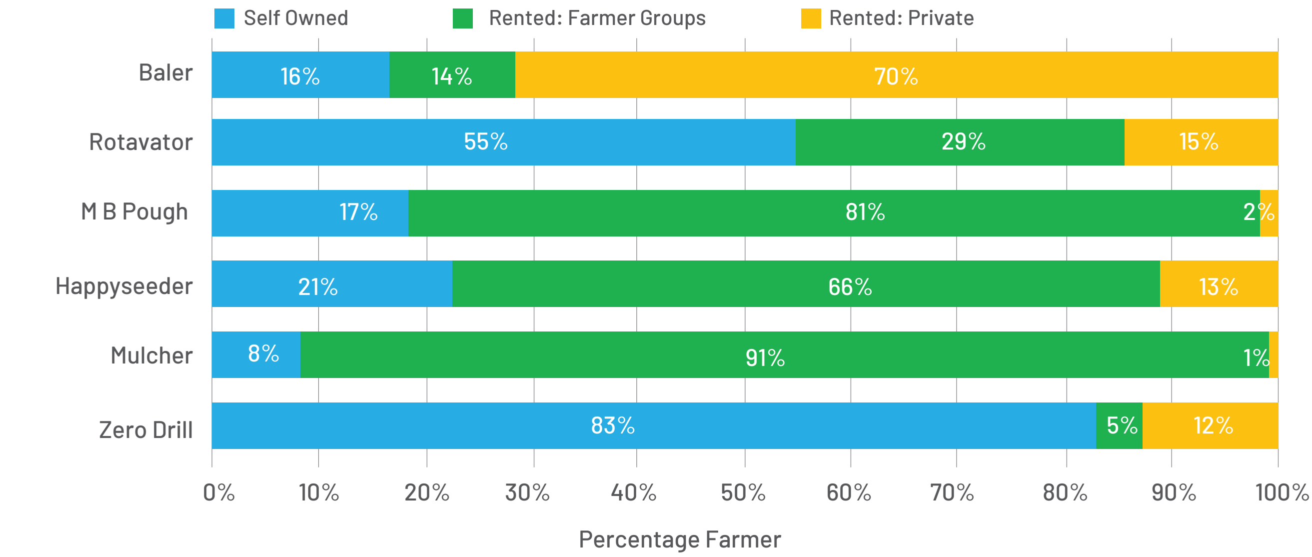


Figure 4: B. Source of tool preferred by farmers (2020)



Source: CII Cleaner Air Better Life (2022) analysis

Comparing the scenario for 2019 and 2020 figure 4a & 4b there are few learnings which are highlighted,

- Dependence of farmers on farmer groups for tool rental have improved over the year, a greater number of Rotavator, Happyseeder, Mulcher, M B Plough are being accessed from farmer group. This highlights the success of shared economy modal and improved confidence of farmers on community tool banks
- Zero drill majorly utilised for conventional practice i.e., after complete and open burning of remaining biomass are owned by majority population of farmers across the intervened area
- There is steady fraction of agriculture tools for sowing (i.e., rotavator, Happyseeder, superseder) are accessed from private service providers who are medium to large farmers from same or nearby village utilising tools for additional income generation.

Over the years farmers have tried and tested diverse tool combination across their operational landholdings. Based on this experiential learning and driven primarily by convenience and cost factors, farmers then decide the most optimal method or tool combination for CRM. Table 3 shows major tool combinations adopted by farmers in 2020 and 2019. To simplify the overall picture, the table 3 consists of only major tool combinations which constituted a share higher than 1% of farmer population or all sampled farmers in this case. In-situ management method- mulching, where happyseeder is used as a key tool, has merely sustained the test of time with somewhat consistent share among alternate practices over last three years of intervention. Major change in preference of tool combination is seen with wide scale adoption of newly introduced super seeder. With a humble start of less than 1% share, among those who are undertook straw incorporation in 2019, Super seeder has become the most preferred tool for in-situ management in 2020. While super seeder with superior straw mixing capability is fast replacing the use of rotavator in straw incorporation; it requires high horse power (greater than 55HP) tractor which is a limiting factor for most marginal to small farmers. Share of farmer adoption have improved for less fuel and time-consuming practices of straw mulching, there are some underlying farmer concerns based on past experience which hinder most fruitful decision making.

Table 3 highlights order of preference of tool combinations implemented by farmers. Major tool combination adopted by farmers are influenced by numerous factors including fuel consumption, tool availability, farmer preference, local soil condition. Whereas, farmers pick options with least fuel consumption until other option is convenient and less time consuming.

With a humble start of less than 1% share, among those who are undertook straw incorporation in 2019, Super seeder has become the most preferred tool for in-situ management in 2020.

Table 3: Major tool combinations preferred by farmers adopting different practices of paddy straw management

Practice	Method	Tool Cominations	Percentage Share of Tool combination among method 2019	2020
Conventional Practice	1. Crop Resdiue Burning	1.1 Cutter + open burning + Rotavator-cum-SD	59.51%	67.65%
		1.2 Cutter + open burning + Disk harrow + Culitvator + Leveller + Zero-Till Seed Drill (ZTSD)	40.49%	32.35%
Alternative Practice-Is-situ	2. Mulching	2.1 Happyseeder	43.00%	60.67%
		2.2 Mulcher + Happyseeder	36.00%	30.34%
		2.3 Supper SMS + Happyseeder	21.00%	8.99%
Alternative Practice-Is-situ	3. Straw Incorporation	3.1 Superseeder	0.34%	42.12%
		3.2 Rotavator-cum-SD	72.00%	37.18%
		3.3 Mulcher + Reversible MB plough + Rotavator-cum-SD	15.00%	9.10%
		3.4 Mulcher + Rotavator-cum-SD	5.00%	6.65%
		3.5 Mulcher + Superseeder	0%	4.09%
		3.6 Reversible MB plough + rotavator-cum-SD	1.00%	0.24%
		3.7 Rotavator + ZTSD	4.00%	0%
		3.8 Super SMS - rotavator-cum SD	3.00%	0%
Alternative Practice-Ex-situ	4. Baling/ collection	4.1 Cutter + Raker + Baler + Rotavator-cum-SD	65.17%	78.86%
		4.2 Cutter + Raker + Baler + Superseeder	0.00%	12.00%
		4.3 Cutter + Raker + Baler + Disk Harrow + Culitvator + Leveller + ZTSD	34.83%	7.43%
		4.4 Cutter + Raker + Baler + Happyseeder	0.00%	1.71%

Source: CII Cleaner Air Better Life (2020-22) analysis

4.1.2 Community-scale Adoption of Burning-free Practices

Majority of CII intervened farmland and farmers (82% and 72% respectively) are located across four districts of Punjab. Remaining are located (18% farmland and 28% farmers) across three districts of Haryana. Assessment of data from these 172 villages across seven districts of Punjab and Haryana indicates that 2160 sampled farmers divided their operational landholdings into total 2367 fields for adoption of various farming practices. Approximately, 10% of all farmers divided their operational landholdings into number of 2-3 plots under different practices to reduce risks associated with new technologies or agricultural practices.

Technology adoption across these 2367 fields under different crop residue management practices is assessed to build the full picture of technologies/ practices adoption in 2020 (See Figure 5). From analysis of the primary data, it is deduced that 85% farmers of total 27863 farmers in 172 villages (95% confidence level and ±2.03% margin of error) practiced new methods substituting conventional method involving open and complete burning of rice straw. This is equivalent to 87% of intervened farmland where complete and open burning of rice straw was avoided. While only 15% farmers resorted to open and complete burning of rice straw, almost 8% of the farmers practiced partial straw management. Partial adoption of in-situ management takes place in fields where 100% direct reuse of straw is not feasible due to various operational challenges at the field. Field data indicates that on average 30% agricultural waste is heaped and burnt in this method, while majority (70%) of biomass is incorporated back into soil (CABL field survey data validated with FGD) under this hybrid method using the tools such as- superseeder, rotavator or reversible mould board plough.

Total 71% of all farmers practiced in-situ management including mulching and straw incorporation. Straw incorporation constitutes the largest share of in-situ management practices at 63% of all farmers, while a sizeable number of farmers (8%) relied on mulching for in-situ management. There are 6% farmers who relied on baling out the straw due to limited feasibility of in-situ management methods on their fields.

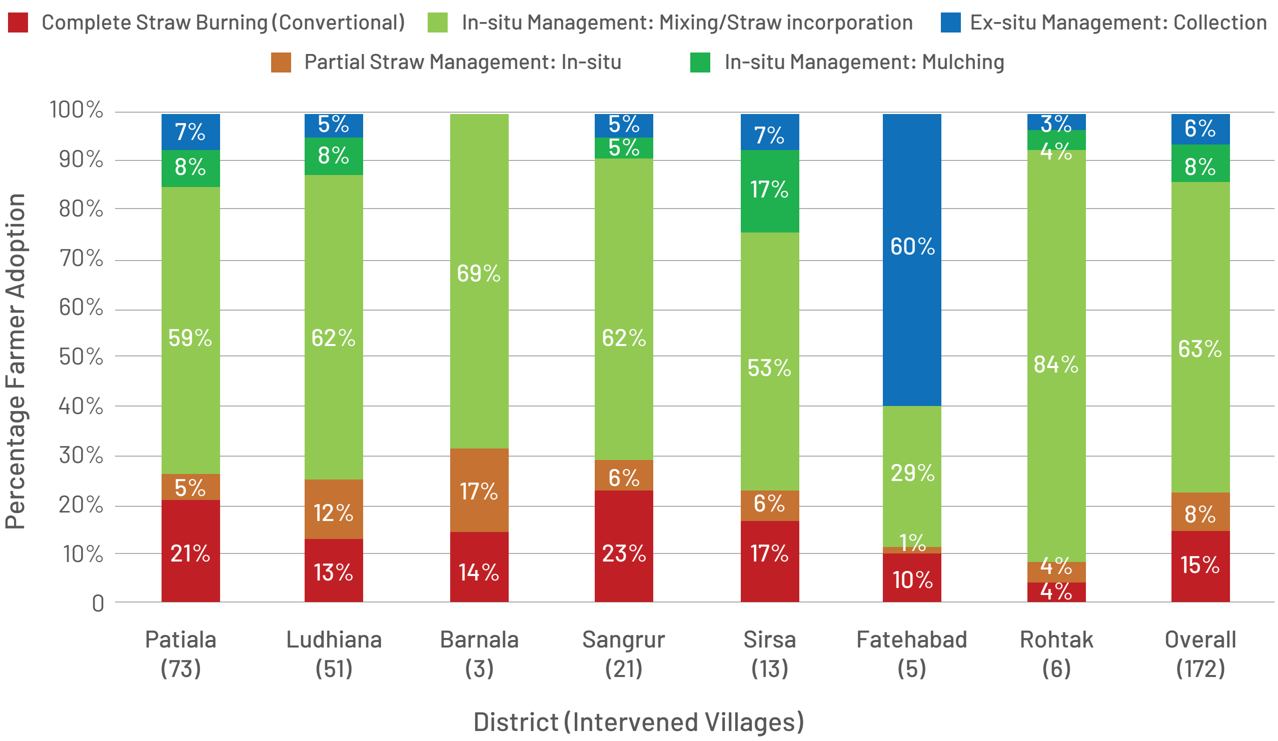
As shown in Figure 5, the overall results on technology adoption varies significantly across districts. In Rohtak, the extent of burning is limited to 4% with maximum extent in Sangrur and Patiala at 23% and 21% respectively. A significant number of farmers in districts Barnala (17%) and Ludhiana (12%) practiced partial straw management. Significantly higher baling (60%) is observed in Fatehabad due to-

- Hard soil conditions which make operation of in-situ implements difficult for farmers
- Higher straw-to-grain ratio associated with specific rice varieties e.g. PB1401 grown in this region

As pointed out later in this study, ex-situ is still not cost-effective proposition to farmers and Haryana Government's initiative to provide a direct benefit of one thousand rupees per acre to farmers is the major reason for significant adoption of Baling in Fatehabad. More impact is seen in Fatehabad cluster as compared to Sirsa and Rohtak due to inherent issue with technical feasibility for in-situ straw utilisation and consumption of baled straw in nearby biomass-based power plant.

Relatively higher incidents of burning as well as partial burning were recorded in Sangrur cluster of Punjab. That's mainly because it takes time to build farmer's confidence in recently intervened areas for a community- scale transition. Local community leaders supported the program and tried to move towards more sustainable practice in this year while also moving from complete and open burning of straw to partial straw management. Overall, relatively higher burning incidents are observed in Punjab geographies compared to Haryana in 2020.

Figure 5: Adoption of Crop Residue Management practices by farmers across seven clusters



Source: CII Cleaner Air Better Life (2022) analysis

Straw incorporation is a major adopted technique. Majority of farmers embrace straw incorporation or mixing because of one or more factors listed below.

- It is the closest to the conventional method involving extensive tillage. In the case of rotavator/ superseeder, tillage is limited to the topsoil. MB Plough may even involve deep ploughing to incorporate and mix the above-ground as well as below-ground biomass into the soil.

- Farmers are familiar with operation of rotavator which also get utilised in the convention method. On average, 68% of farmers using conventional method utilise rotavator across intervened areas. Mulching of paddy straw, on the other hand, require certain level of knowhow in order to achieve desired results.

- Newly sown field is not covered with the layer of mulch which hinders farmer's ability to see the early germination of wheat. This is found to be a major preceptory barrier for adoption of mulching.

These factors, documented at focussed group discussions in intervened villages, lead to farmers even losing confidence in Mulching practice in first year itself and resort to other practices. Despite this, significant farmers who attained good results with mulching are still preferring it. Leading factors for adoption of mulching are-lesser time for field preparation, lower cost of cultivation, lower fuel cost, and reduction in weed occurrences due to no tilling.

Majority of farmers (55%) in the Sirsa cluster preferred baling in 2019 since there was a prospect that the baled straw may be sold to a neighbouring straw scarce state (Rajasthan) for making animal fodder. But most baled straw was not utilised leading farmers resorting to in-situ options this season. In Fatehabad cluster there is significant adoption of baling practices which indicates that farmer value straw as a resource provided supply chain is well established.

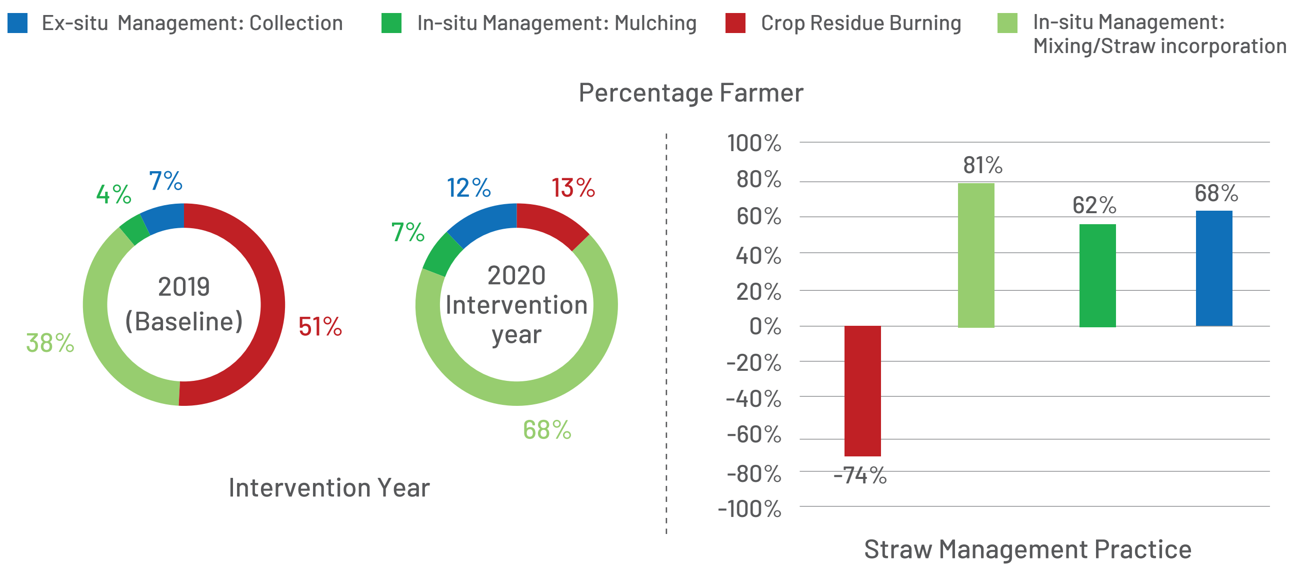
The paddy variety also hugely impacts the farmers overall choice of practice. Significant number of farmers in Haryana (Fatehabad and Rohtak) who opted for shorter duration varieties of rice PB-1509 (See Annexure 2) are more likely to move towards sustainable practices as straw management becomes relatively easier. However, even in these cases, proper awareness and capacity building is required to move away for conventional practices.

Figure 6 shows how rice straw was managed in the baseline across clusters (2019) and year of intervention (2020) for which impact assessment is carried out. On the basis of this information, pace of technology adoption was calculated. Figure 6 also provides an overview of this for 172 villages and shows the actual impact of CII's CRM programme in 2020. Overall impacts on reduced extent of burning or adoption of new practices across Punjab and Haryana include-

- Overall, the crop residue burning reduced from 51% in the baseline year (2019) to 13% in 2020 across intervened areas. This meant overall 74% decline in extent of rice straw burning across intervened geographies.

- The overall adoption of improved CRM practice went up by 77% in intervened area. This included significant increase in straw incorporation/mixing by 81% along with nominal increment of mulching as well as baling at 62% and 68% respectively in one year.

Figure 6: Impacts of CII programme in 2019 for curbing crop residue burning and accelerating adoption of improved Crop Residue Management (CRM) practices



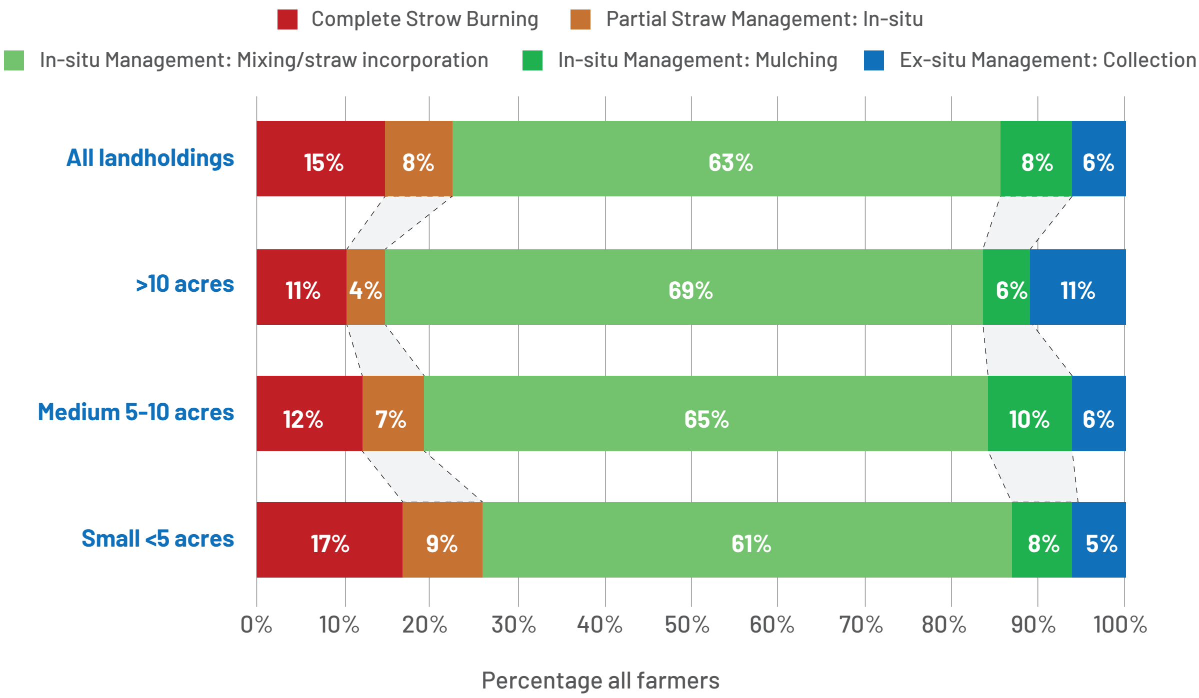
Source: CII Cleaner Air Better Life (2022) analysis

4.1.3 Inclusive Adoption of New Technologies & Practices

As shown in Figure 7, significant number of farmers belonging to different size classes participated in the programme and adopted new practices in the 2020 season. Overall, 83-89% farmers belonging to different size classes participated in the programme to adopt improved crop residue management practices including in-situ and ex-situ management practices. Also, as evident from primary data in Figure 7, the partial burning incidents came down heavily across different size classes from 34-35% in 2019 (refer annexure 3) to 4-9% in 2020. Latter is due to the fact that challenges associated with 100% utilisation for in-situ has been overcome with large-scale adoption of 'superseeder' in 2020. Superseeder has higher capability for incorporating straw in the fields where 100% in-situ treatment was not possible earlier with the tools such as rotavator or happyseeder. However, the key drawback is commensurate requirement for high horse power (hp) tractor: 55 hp and higher, as compared to the happyseeder which can be operated with a 50hp tractor.

The adoption of new practices is relatively lower for the marginal to small farmers (with landholding less than 5 acre) with 17% small-marginal farmers still relying on CRB, compared to 11-12% medium or large farmers (landholding greater than 5 acres) with farmers relying on CRB in intervened communities. This indicates that there is yet room for improvement in the programme delivery to make adoption of environment-friendly practices cost-effective for marginal and small farmers. Also, cost-effectiveness of ex-situ management practices is especially challenging for farmers. It is also evident from the fact that only 5-6% of marginal-small and medium sized farmers could use baling in 2020 as compared to 11% large farmers who used ex-situ to manage surplus rice straw.

Figure 7. Adoption of practice across land-holding size classes in the intervention year 2020: 172 villages



Source: CII Cleaner Air Better Life (2022) analysis

The following conclusions can be drawn after assessing the adoption of different practice across farmer size classes in across intervention years (refer annexure 3)

- The adoption of sustainable practice remained almost the same over the years with 86% adoption in 2018 to 85% in 2020 with improvement in adoption of in-situ management i.e., 79% in 2020 as compared to 72% in 2018

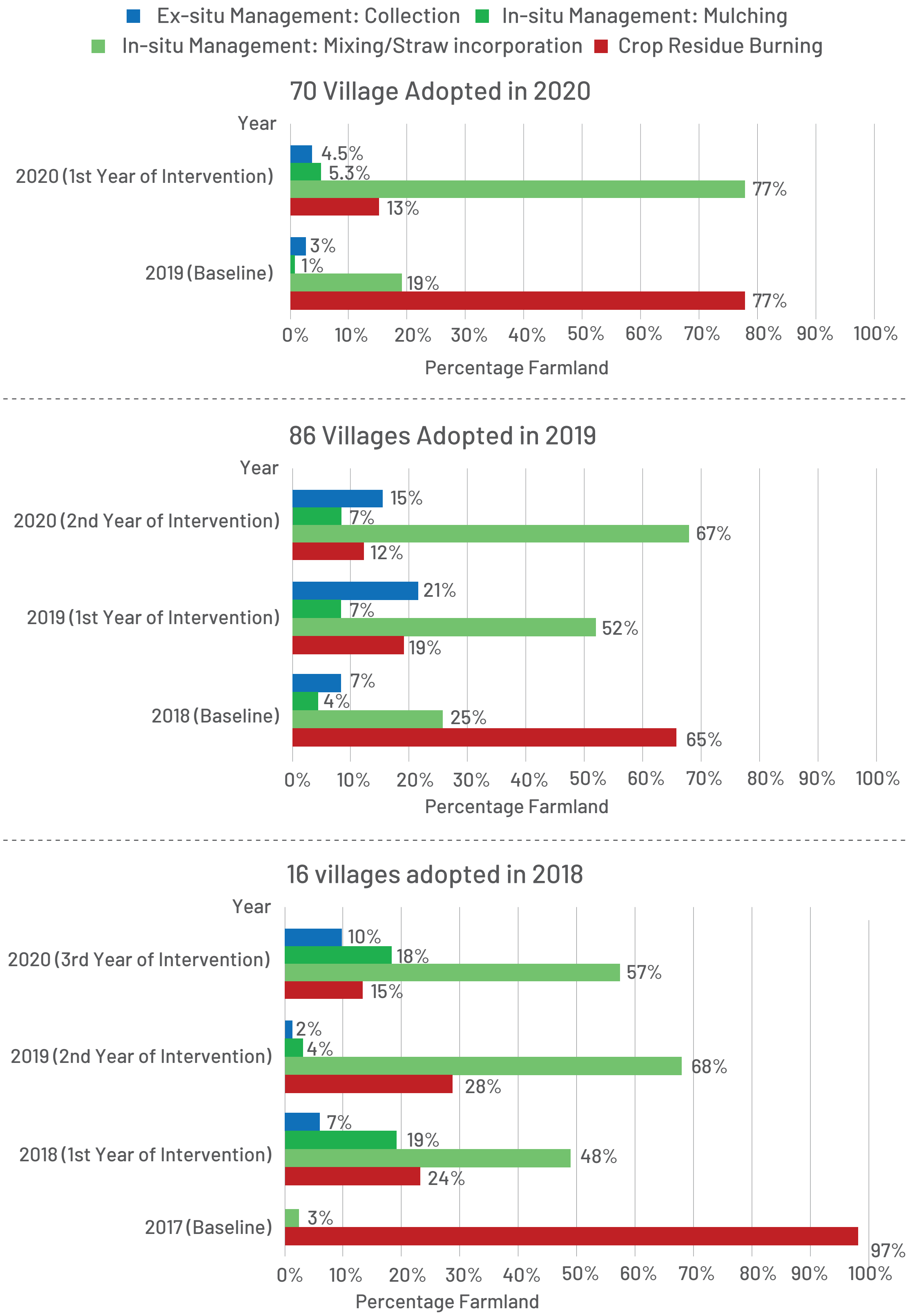
- Though the overall adoption of sustainable practice remained the same the share on partial straw management as well as ex-situ have declined across farmer size classes highlighting the fact farmers are progressively realising the benefits of in-situ management of paddy straw

- Second year the adoption of partial straw management increased significantly which indicates farmers losing confidence in in-situ management practice especially due to few cases of poor results especially after adoption of mulching practice though the impact on crop yield is insignificant in most cases which can also be associated variety of field specific factors

4.1.4 Sustained Adoption of New Technologies & Practices

Since the onset of CABL CRM programme, it has expanded to significant areas of paddy producing states and this gave us the opportunity to take stock of the technology adoption over the years since the first year of intervention.

Figure 8. Development of adoption of crop residue management practice across cluster adopted in three years: 2018, 2019 and 2020



Source: CII Cleaner Air Better Life (2022) analysis

Figure 8 shows how rice straw management situation evolved across villages which were intervened at different times. This is summarised below for three different sets of intervened villages. Geographical locations of these three subsets of villages can be traced in the figure 1 showing villages by the year when they are intervened.

Villages with three years of intervention: 16 villages intervened in 2018

For villages adopted in 2018, significant decline of complete burning is seen from 97% of total farmland in 2017 (baseline year) to 15% in 2020 which is third year of intervention. The visible dip in adoption of sustainable practices in 2019 is seen as a result of isolated incidents of pest problems in mulched fields, higher perceived risks associated by farmers with mulching or happyseeder and limited options at that time. This weather- induced phenomenon did affect 1-2% of farmers adopting mulching on a varied scale, this had insignificant effect on the overall or average crop yield from mulched fields. While mulching has maintained significant fraction at 19% of all agricultural practices in 2020, straw incorporation has quicky grown as major alternate to replace conventional method of burning. On exclusive basis, 72% of all intervened farmers in these geographies sustained newly adopted practices.

Village with two years of intervention: 86 villages intervened in 2019

A sustained reduction in conventional method with burning at 65% in baseline year to 19% in 2019 to 9% in 2020 is seen. Higher amount of baling is evident in these villages due to the fact that balers were provided on farmers' demand under CII's CABL programme in 3 out of the 6 intervened clusters. But baling has recently faced push back from farmers due to fluctuating market demand for bales and higher cost involved in baling out the straw. Significant farmers have therefore moved from ex-situ or baling to in-situ straw incorporation method with newly introduced' superseeder'.

Villages with one years of intervention: 70 villages intervened in 2020

For the 70 villages adopted in 2020, extent of burning declines from 77% in baseline year to 12% in 2020. Major portion of farmland, 77%, is manged by straw incorporation with 5.3% by mulching and 4.5% by ex-situ method: baling. Lateral expansion across intervened clusters in 2020 and spill over from previous years' work resulted in a significant increase in the adoption of sustainable practises in these villages in the first year itself.

4.1.5 Capacity Building for Clean Air and Healthy Soil

In partnership with Punjab Agricultural University, Ludhiana (PAU), Haryana Agriculture University, Hisar (HAU) and active support from District Agriculture Offices and KVKs, CII Foundation organised several technical trainings and workshops in the project areas involving scientists, key government officials and machine manufacturers as resource persons.

Besides these significant number of communication and behaviour change activities took place in villages involving door-to-door campaigns, meetings with local stakeholders, awareness rallies with school children, awareness messaging from village gurudwaras and meetings of village-level Nigrani (Monitoring) Committees. Village level volunteers are deployed to provide on-field technical handholding support to farmers during and after the harvest season. CII facilitated Machinery Manufacturers to provide demonstration and trainings on technical aspects of machinery operations. Experienced farmers are engaged to share their experiences and motivate other farmers in nearby villages. Key activities by CII and its partners are summarised in the table 4 along with numbers of each event held in 2020 across intervened geographies of Punjab and Haryana (See Figure 9 and Table 4).

Figure 9: Field activities including farmer training, awareness drives, on-field tool demonstration etc

Source: CII Foundation 2022

Village level volunteers are deployed to provide on-field technical handholding support to farmers during and after the harvest season.

Table 4: Details of Awareness Building Activities, Trainings and Workshops Conducted in 2020 across 172 intervened and 28 demonstration villages

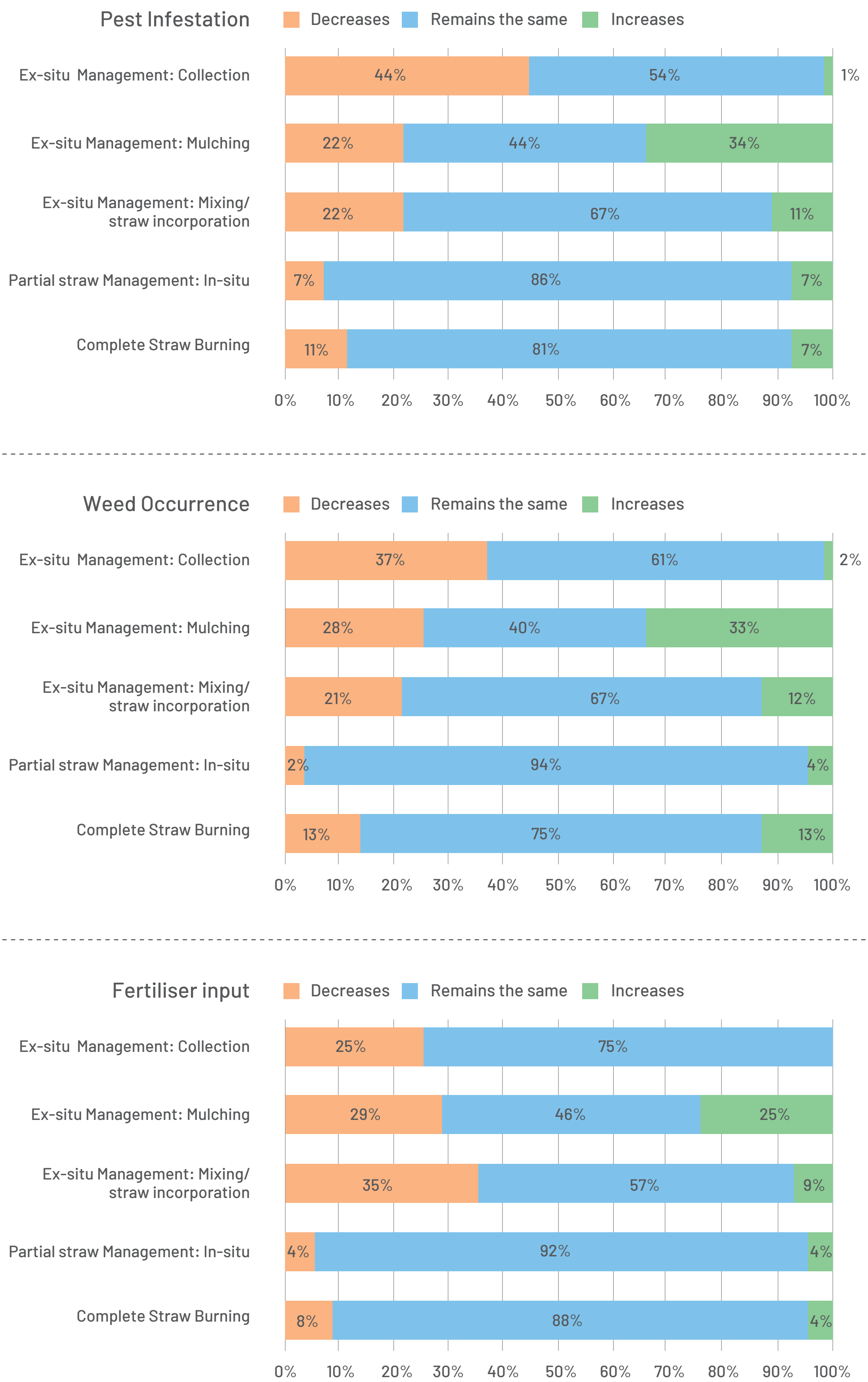
Behaviour Change and Capacity Building Activities	Punjab	Haryana
Village-level meetings with farmers	300	50
Field meetings with farmer groups	1080	120
Cooperative Societies' meetings with key village members	130	30
Awareness rallies and sessions	25	5
Nigrani Committee meetings	60	10
Wall Paintings for public messages	2-3 per village	
Mobile awareness van	1 van per day throughout the harvest season	
Awareness messaging through Gurudwaras and Panchayat offices	Everyday	
Door to door campaigns & field visits by volunteers	2000	500
Trainings in partnership with State Agriculture Departments	30	10
Trainings by State Agriculture Universities & Krishi Vigyan Kendras	7	3
Webinars byagricultural scientists and project team		8

Source: CII Foundation 2022

To evaluate effectiveness of these activities, farmers' perception and awareness on crop residue management and associated change in agricultural practices are assessed in this evaluation by getting farmer responses on a Likert scale. Figure 10 shows farmers' response on pest infestation and weed occurrences. Data clearly shows that farmers confidence on improved crop residue management practices has increased significantly over the years, but there is still a room for improvement as significant farmers maintain the neutral position.

Although, the perception of benefits associated with in-situ management methods is higher in general across methods, an underlaying concernand higher perceived risk associated with mulching is also visible. Besides association of higher risks with in-situ management practices, exaggeration of benefits in favour of ex-situ management practices is also seen as baling remains a limited option due to higher cost for farmers and limited demand. These findings suggest there is need of targeted knowledge support to farmers with evidence from field.

Figure 10: Farmer perception towards pest infestation, weed occurrence and fertiliser input in the wheat crop under different sets of rice straw management practices



Source: CII Cleaner Air Better Life (2022) analysis

4.2 Economic Impacts

This section presents key evidence established from multi-year field data on economic benefits of improved crop residue management practices which are primary motivation for farmers to change their practice. Reusing the straw in-field improves the system-wide performance of agriculture extending beyond simple nutrient recycling. Key economic impact evaluated by this study include short-term as well long-term impacts as listed below.

- **Enhanced Crop Yield Benefits** which indicate overall soil health improvement due to no open burning on fields
- **Fertiliser Savings** incurred from nutrient recycling from biomass application to soil
- **Chemical Savings** especially weedicide savings incurred from less extensive tillage regime and less topsoil disturbances resulting from in-situ management
- **Fuel Savings** from In-situ management due to significantly lesser number of tool runs between harvesting rice and sowing wheat compared to conventional method
- **Cultivation Cost Savings** incurred by farmers under the shared-economy model with farmer groups

Out of the listed impact categories above, fuel and cultivation cost savings manifest at the time of intervention itself due to less extensive tillage and as a result, lesser number of tools or tool runs on ground (compared to the conventional method). Our evidence shows that yield benefits become visible in relatively short span of 1-2 years, while it takes 2-3 years to realise any savings in fertiliser and chemical inputs.These benefits are quantified from farmers' data and analysed in this section but before presenting these results, few success stories from field in Punjab and Haryana are captured in box 1 and box 2 to set a better context of these from the farmer perspective. This is especially important as not all individual-level benefits get captured in aggregated or averaged information across farmer samples.

Box 1. Success Story of Progressive farmer in intervened villages of Sirsa, Haryana

Progressive farmer **Chhinderpal Singh** (left) is seen attending to a query from his fellow farmer in Sirsa. He has been practicing mulching and no-tillage on 30 acres farmland for 8 years. He has been crucial in Cleaner Air - Better Life's efforts to convince farmer communities to switch to sustainable agriculture practices in the Rania Tehsil of Sirsa, Haryana. Chhinderpal has himself managed to reduce dependence on inorganic fertiliser from 150kg/acre to 30-35 kg/acre over these years. Also, his earlier requirement of 10 kg Zn, 40 kg K and 2kg S micronutrients is now completely obliterated due to soil rejuvenation and higher microbial activity.

Due to no disturbances to top-soil under no-tillage regime, his weedicides cost (which is field specific and was approx. INR 500 per acre at the time he was burning) has come down to zero. Fuel or diesel cost, which is especially relevant due to very high fuel prices in 2021, is 1/3rd less compared to conventional practice (involving burning) for the tool combination he uses to manage straw from 1401 basmati rice- mulcher & happyseeder.

Despite 8 years of returning biomass back to soil, his field is tested to have moderate soil carbon as a result of mulching. Chhinderpal is a pioneer and role model to other farmers. He is testament to the fact that sustainable agricultural practices such as mulching & no-tillage work in long-term for clean air as well as cooler planet.

Source: CII CABL 2022

Box 2. Success Stories from intervened villages in Patiala, Punjab

Gurinder Singh is from Khedimania area in Patiala intervened by Cleaner Air - Better Life since 2019. For past three years, he has been using happyseeder to recycle straw back to the soil on his 5 acre field. Over the years, he has seen 1/4th reduction in fertiliser use and 20% reduction in use of weedicides. His overall diesel consumption came down substantially from 200 litre to mere 35 litre as he is only using one tool, that is happyseeder, now as compared to multiple tool runs and extensive tillage he followed previously along with open buring. He is very positive about happyseeder and so are the other farmers in Khedimania who are now sowing approximately 600 acre farmland with happyseeder.

Jagjeet Singh is from Mungo village in Nabha Tehsil of Patiala, Punjab intervened by Cleaner Air - Better Life. He has been recycling rice straw back to soil on his 7 acres farmland for last 2 years using superseeder. He is now spending 1/3rd less on fuel, 1/4th less on fertiliser and almost half on chemical inputs for suppressing weed in his plots.

Gajjan Singh is from Birdwal village in Nabha Tehsil of Patiala, Punjab. He has been managing rice straw on his fields spanning 40 acre without burning since the onset of CII Cleaner Air - Better Life CRM programme in 2019. Recently, he switched from happyseeder to superseeder for doing so. He has been getting a consistent yield of approximately 22 quintal per acre with both methods and only reason he switched from mulching to straw incorporation recently, he says, is perceptory and the ability to be able to see the wheat germination at early stage.

Ravinder Singh is from Mungo Village in Nabha block of Patiala, Punjab. He has not burnt stubble for last 2 years. He mentioned that on our fields, we first used the Mulcher and then the MB Plough, and this time we didn't have to spray any fertilisers (micronutrients) on the crops. This is the greatest benefit for the farmers; with the green manure, the crops become stronger and more resilient to diseases. This also prevents damage to the crops and human health due to excessive use of fertilizers. It is quite economical and helps save on the costs incurred on the fertilizers. CII has invested and provided the cooperative societies with machines to manage the stubble at a very reasonable rent. The machines are helping us keep the environment and ourselves healthy. Moreover, these new practices are also helping in enhancing the soil quality and germination.

Source: CII CABL 2022

4.2.1 Improved Crop Yield

Production or yield of rabi crop sown immediately after rice is major factor affecting farmer's choice of crop residue management method. A major emphasis of programme implementation after harvest rice is therefore to ensure higher or at least the same level of crop yield for farmers under new set of agricultural practices. Activities during rice harvesting which impact the immediate wheat crop and its yield (quintal wheat per acre). The wheat yield is therefore used as benchmark to measure programme success. Our study establishes that crop yield gain from switching away from years of burning to sustainable agricultural practices is not immediately visible and it takes few years for soil health benefits to manifest after application of crop residue due to complex soil dynamics at play in agriculture. The yield changes are therefore evaluated for cross-sectional as well longitudinal data.

- **Inter-practice comparison for cross-section of farmers intervened in 2020:**

  Yield in plots under alternate practices is compared against the yield recorded in plot under conventional practice for the agricultural year 2020-2021. Cross-sectional yield data from Rabi season of 2021 shows substantial yield difference for farmers who burnt rice straw to manage fields and farmers who adopted alternate CRM practices (See Figure 11). The key results from this analysis are-

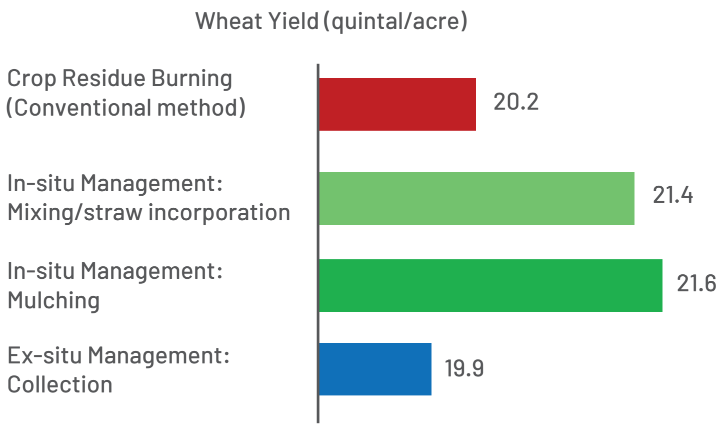
  I. Mulching provides the highest yield to farmers in next crop compared to plots where rice straw was cleared with open burning in 2020: 7% higher yield recorded during wheat harvesting in subsequent season-Rabi.

  II. Moreover, 6% higher yield is achieved by farmers practicing straw incorporation as compared to those who are still resorting to open burning for managing post-harvest rice straw.

  III. As significant portion of farmers are practicing straw incorporation in intervened areas, average yield benefit for all plots under in-situ management practices is observed to be at the same i.e. 6% higher than open burning or CRB as a management method

  IV. For the case of ex-situ management or baling, yield is found to be slightly lower (-1.48%) compared to plots under CRB.

Figure 11: Wheat yield under different rice straw management practices in 2021



Source: CII Cleaner Air Better Life (2022) analysis

- **Inter-practice comparison of longitudinal trend with sustained adoption of 3-years:**

Alternate practices are further evaluated for yield changes over last three years (See Figure 12). Farmers following conventional practice (CRB) for relatively longer periods are found to be getting a consistent yield of '20.2 Quintal Wheat grain per acre' on average, as indicated by red bar in Figure 12. Comparison with this benchmark for wheat yield gives following results-

I. Farmers practicing in-situ crop residue management practices obtain higher yields in general. The highest yield gain of 10% (10% higher when compared to conventional practice: CRB) is observed for' mulching' among all alternate practices.

II. Yield from plots under mulching is found to either stay at the same level or progressively increase with sustained adoption.

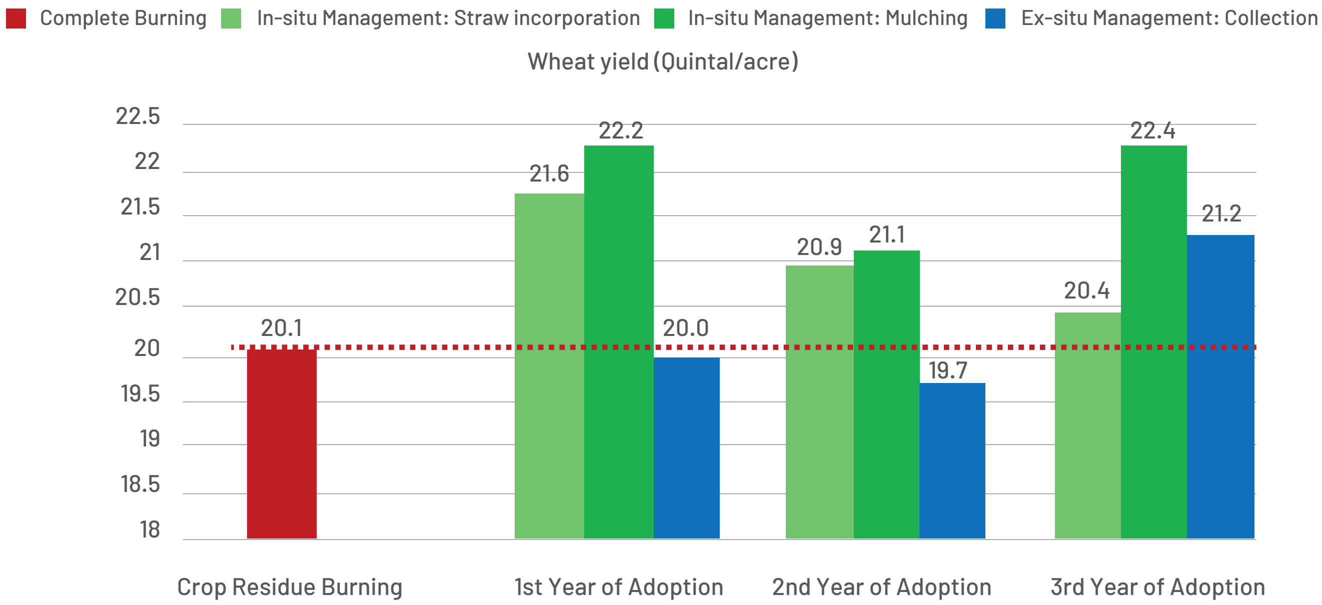
III. Although yield for plots under straw incorporation is found to be higher than conventional method or CRB, it progressively declines, at 2-3% per year, with the adoption. As this trend is limited to 3 years and is not from the same plots, this might have been due to other external factors.

IV. Although slightly higher yield is observed for ex-situ method: collection or baling in the year 2020, on average the yield across 3 years is only slightly higher (+0.5%) when compared to the conventional practice: CRB.

It is clear from the above analysis that while yield gain observed across in-situ practices varies with practice and sustained adoption. Although, mulching as well straw incorporation may seem comparable at 6-7% yield gain for all farmers in 2020, mulching emerges as a clear winner with higher gains in long-term with sustained adoption. Also, it is clear from the study that direct reuse the straw at field yields highest benefits for farmers irrespective of the opted method. But declining trend on yield from straw incorporation is worrying, although it is still (after three years) at a level which is 1.5% higher than conventional method. This needs to be monitored and tracked closely in the future, especially so with the progressive farmers who have been utilising these practices for longer time horizons, say 8-10 years.

Above key findings from the field corroborate well with other studies in Punjab and Haryana which observe that in-situ management of rice straw improves the wheat crop yield by 2-10% (Kumar et al 2015, Sidhu et al 2015, Aryal et al 2016, NAAS 2017, Kakraliya et al 2018, Ram et al 2018, Jat et al 2019). Noteworthy examples from literature also indicate no substantial changes in yield at early stage, particularly in the first year of technology adoption (Sidhu et al 2015, Ram et al 2018). This correlates well with need for more community level efforts for sustained adoption of new practices in initial years of the programme. The improvement is gradual and at best, it takes couple of years since the first year of adoption for the yield benefits to manifest fully.

Figure 12: Wheat yield under different management practices and variation with sustained adoption



Source: CII Cleaner Air Better Life (2022) analysis

4.2.2 Inorganic Fertiliser Savings

Nutrient recycling by diverting the straw back to soil reduces dependence on inorganic fertilisers in long run. Burning of one tonne rice straw depletes 400 kg of organic carbon, 50-70% of beneficial micro-organisms in topsoil, 5.5 kg Nitrogen (N), 2.3 kg Phosphorus (P), 25 kg Potassium (K), 1.2 kg Sulphur (S) (Kumar et al 2019, Kaur et al 2021, PAU 2021). These nutrients are released into the atmosphere in the form of various air pollutants causing environmental pollution as discussed under the section 4.3 on environment impacts. Avoided burning leads to commensurate nutrient value addition to the soil. In consecutive 2-3 years of mulching or incorporating the rice straw in the region, 15-20% direct fertiliser savings are reported in the region (Kumar et al 2015).

As reported in 2019-20 study, nitrogen immobilisation[4] leads to higher consumption of urea or nitrogen fertiliser in the first year due to imbalance in C/N ratio whenever there is shift from conventional practice (many years of crop residue burning in his/her fields) to in-situ application of biomass or crop residue.It is a temporary phenomenon and typically manifests at early plant growth stage, within a month of wheat germination, in the first year of adoption. The trend reverses as the carbon in paddy straw undergoes decomposition in 1-2 months and is alleviated with application of urea or nitrogen fertiliser. This phenomenon was, in fact, very common in intervened areas and farmers are in fact advised to apply urea (not exceeding 1/6th of total requirement for wheat crop) in affected fields whenever yellowing of wheat plants happen as a result of nitrogen immobilisation. Phenomenon is linked to increase in soil organic carbon which ultimately leads to higher microbial activity, healthier soils, and higher use efficiencies of fertiliser and water with higher agricultural productivity in long-term.

Figure 13 shows the average fertiliser usage by all farmers in 2020 separately for Di-Ammonium Phosphate (DAP) as well as Urea. Urea is the major fertiliser input during wheat plant growth, whereas Di-Ammonium Phosphate (DAP) is applied once at the time of sowing seeds. DAP is typically applied in specific weight ratio to the seeds at the time of sowing and this requirement varies as per the sowing method. Only urea as major fertiliser input in subsequent crop, which is wheat, is analysed here. But case studies as shown in the Boxes 1 and 2 show us that benefits on ground become more pronounced with sustained adoption of in-situ management.

Only urea input is considered in subsequent text for inter-practice comparisons. Aggregate figures for DAP and urea consumption in 2020 as shown in figure 13, seems higher for alternate methods (+2.8% for mulching, +5.1% for straw incorporation, and +9.7% of ex-situ/collection). But only when we look at similar figures for farmers with varying degree of experience (1, 2, 3 and >3 years of adoption[5]), it becomes clear that this effect is predominantly due to large number of farmers adopting new practices for the first time (55%) and in-situ management practices rather lead to lower dependence on inorganic fertilisers in long-term.

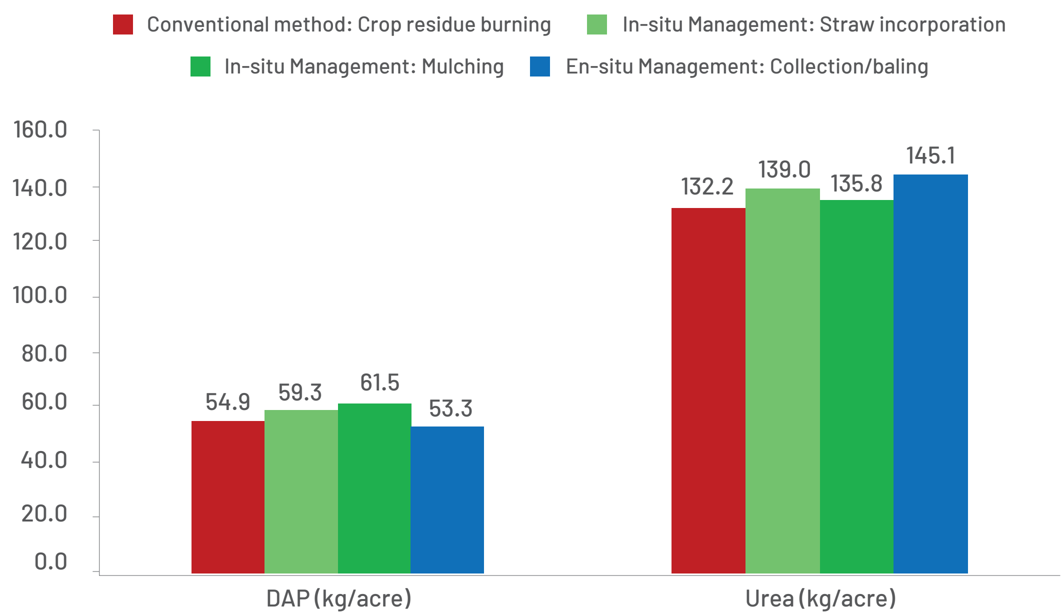
The Figure 14 shows the urea consumption trend for farmers adopting and sustaining different rice straw management practices over time and following results are drawn from this on fertiliser savings-

[4]Immobilisation of nitrogen occurs with application of biomass in the field, causing nitrogen deficiency in short-term, as the C:N ratio of the applied straw varies widely from 70:1 to 100:1.

[5]It is worth noting that farmers with 1, 2, 3 and >3 years of adoption constitute 55%, 34%, 8%, 3% of total sample respectively.

- Fertiliser consumption progressively declines with sustained adoption as far as the in-situ management (soil incorporation and mulching) practices are concerned. Fertiliser consumption increases by +3-5% (straw incorporation-mulching) for in-situ management practices in the first year (of adoption) when compared to the baseline figure of 137.5 kg urea per acre[6] owing to soil dynamics. The figure progressively declines for two in-situ management methods subsequently with sustained adoption of three years to reach -6% of the baseline figure.
- Significantly lower inorganic fertilizer use:-4% within first 3 years to up to 24%in long-term (beyond 5 years) is observed for farmers who adopted in-situ management practice: mulching when compared to the benchmark discussed above on the conventional practice involving open and compete burning. It is worth noting that farmers who adopted new practices in the last three years of intervention constitutes majority (97%) of the surveyed farmers in 2019-20 with only 3% progressive farmers who have been following new practice for a period longer than 3 years.
- On the contrary, fertiliser use is found to progressively increase with complete burning (100% biomass) and partial burning (burning limited to 30-40% biomass heaped in the field and utilisation of the remaining 60-70% with appropriate in-situ management method) at 12% and 8% respectively.
- Consistently high urea application of +5% compared to CRB benchmark is observed for farmers adopting collection or baling for straw management and this figure is found to be more or less constant (±1%) throughout the adoption horizon. Application of higher amounts of inorganic inputs correlates with commensurate nutrients in the biomass baled out of the field.

Figure 13: A major fertilisers 'Di-Ammonium Phosphate (DAP) and urea' as used by farmer following different crop residue management practices in subsequent cropping season of Rabi

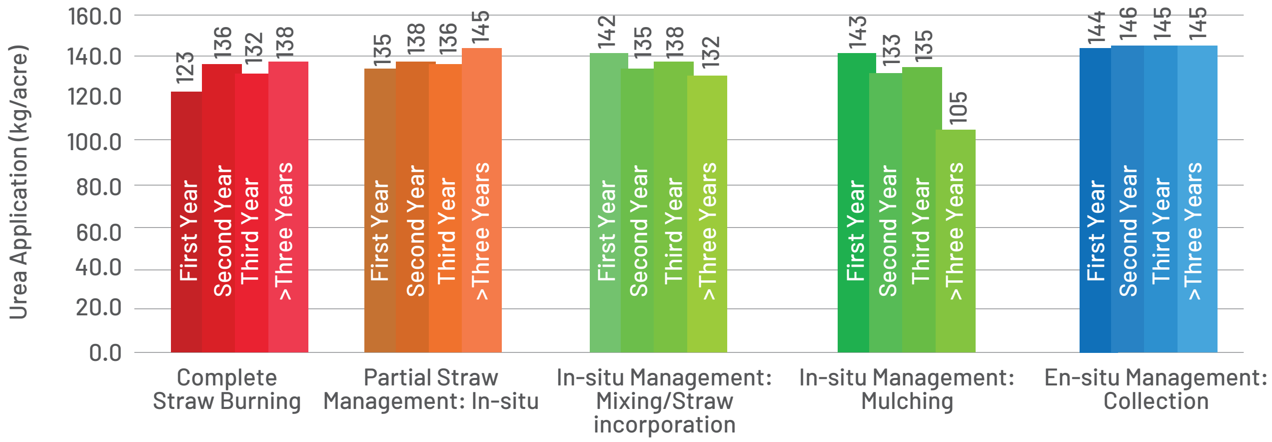


Source: CII Cleaner Air Better Life (2022) analysis

Fertiliser use is found to progressively increase with complete burning (100% biomass) and partial burning (30-40%biomass burning) at 12% and 8% respectively.

[6]Fertiliser consumption under the conventional practice (farmers who practice open burning) is used for comparison and measuring benefits of in-situ management practices. From farmer data, it is found to be 123 kg urea per acre in the first year of crop residue burning and progressively increases to reach an average value of 137.5 kg per acre with more than 3 years of continued crop residue burning.

Figure 14: Urea input by farmers with varying degree of experience on different crop residue management practices



Source: CII Cleaner Air Better Life (2022) analysis

4.2.3 Chemical Savings

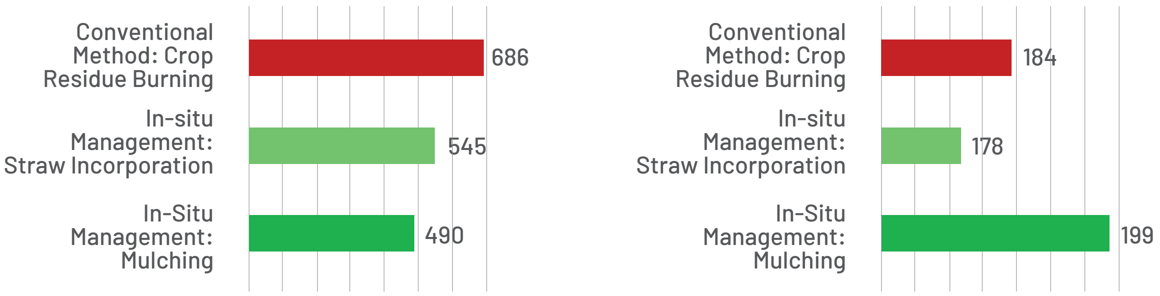
Weeds causes average 20-35% of yield losses in wheat crop in Punjab a leading producer of wheat in the country and the same figure stands at 15-50% for Haryana (Singh et al 2016, Kaur et al 2021). It does so by causing land degradation, impairing grain quantity-cum- quality while substantially increasing the cost of cultivation with requirement of weedicides for supressing weed. One of predominant weed, Phalaris minor, can cause farmer up to 95% yield losses if not checked or suppressed with weedicides application (Kaur et al 2021). Despite successes achieved in effectively controlling Phalaris minor using chemical suppressants or weedicides during the green revolution, the problem has been on rise in recent decades after evolution of multiple resistance against various solutions leading to decline of wheat production in India's breadbasket (Kaur et al 2021). Weed management tactics and strategies therefore need to find a balance between chemical and non-chemical solutions such as in-situ retention of rice straw and evolve in the direction of sustainable weed management.

Another major factor for chemical usage is infestation by various pests. Rodents and insect pests such as Pink Stem Borer (sesamia inferens Walker) have emerged as major pests and risk factors documented on the field for rice straw retention in intervened region. These pests in wheat crop often have their origin in the previous crop from where they carry over with the biomass applied to the field and provide conducive environment for infesting larvae and rodents to propagate. Despite limited damage observed from these factors in intervened areas, pest infestation remains a major concern and risk factors for farmers adopting in-situ management practices, especially for mulching.

Weedicide and pesticide inputs, which is used as a proxy for prevalence of pests and weed in the field, vary with actual field conditions at the village-level, often follows a cyclic pattern, and are affected by the agricultural practices followed by farmers especially for management practices for post-harvest remains of crops or so-called crop residue management practices. It is worth noting that chemical usage patterns not simply indicate the actual risk, but they are also influenced by perceived risk by farmers to a large extent. Excess use of inorganic fertilisers and imbalanced input of chemicals remains one of the key challenges for sustainable agriculture in the region which has been well documented (Vatta et al 2020).

Farmers in the region rely on varied chemical inputs, usually more than one, for supressing weed and pests. Major weedicide applied by farmers are Cloquintocet mexyl, Sulfosulfuron, Pinoxade and Glyphosate with major pesticide applied is Chlorpyrifos. The trend is also followed by change in farmers' preferences over time due to rapidly changing or evolving market for these chemical suppressants. Detailed data on these chemical inputs was collected from sampled farmers in the intervened villages. Actual dosages of various chemicals in millilitre and gram per acre were later converted to aggregate cost of chemical inputs per acre on the basis of existing market prices of used chemical to be able to compare usage patterns and trends across agricultural practices. Farmer-level information is further aggregated into average cost of chemicals on acreage basis to suppress weeds and pests in fields under different straw management practices as shown in Figures 15 and 16.

Figure 15: Weedicide and pesticide cost under different rice straw management practices in intervened areas

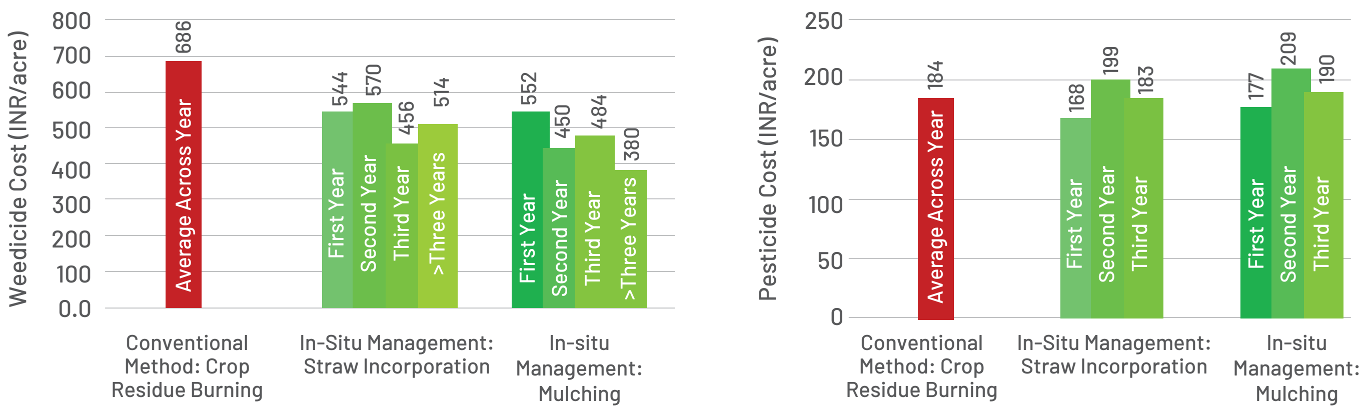


A. Weedicide cost

B. Pesticide cost

Source: CII Cleaner Air Better Life (2022) analysis

Figure 16: Variation in weedicide and pesticide costs with sustained adoption of rice straw management practices in last three years



Source: CII Cleaner Air Better Life (2022) analysis

Key results are plotted in figures 15 and 16 and these findings from farmer data are summarised as below:

1. The in-situ management practices utilise near-zero (mulching with happyseeder) or significantly less intensive tillage (soil incorporation with rotavator/superseeder) causing least disturbance to topsoil in the process of field preparation and sowing the next crop. This change in practices inherently leads to lower occurrence of weed and incurs direct cost savings to farmers due to reduced weedicide consumption. These direct savings are quantified to be -28.6% and -20.5% for mulching and soil incorporation respectively (compared to baseline/CRB which is INR 686 per acre) for all farmers who have been engaged on the programme over last three years from 2018 till 2020. It is worth noting that this is a conservative estimation of direct weedicide savings by farmers, which includes only the cost of chemicals (excluding the cost of their application).

2. Above mentioned weedicides savings go up with sustained adoption and field managed by mulching have seen continuous decline in weedicide consumption or cost from -19.5% for first year of adoption to -45% in fields where mulching is being adopted for more than three years. With sustained adoption of straw incorporation, there is a decline in weedicide consumption or cost from-20.7% in the first year to -25% in field adopting straw incorporation from more than three years.

With sustained adoption of straw incorporation, there is a decline in weedicide consumption or cost from-20.7% in the first year to -25% in field adopting straw incorporation from more than three years.

3. Pesticide cost is observed to have gone up in intervened area to limit the actual damage or cover the perceived risk by farmers especially in the case of mulched fields. When compared with baseline figure for prevalent practice of CRB in the region, the pesticide cost is on average +8% higher for mulched fields, whereas for the fields with straw incorporation the figure is observed to be lower than CRB baseline (-3.3%) which is INR 184/ acre. Looking at year-wise adoption, farmers seem to be adjusting to dynamically evolving situation on field and it can clearly be seen that those who have adopted in-situ management in 2019, utilised more dosage than baseline value, due to prevalent pest issue in 2019 and changes in perception as a result.

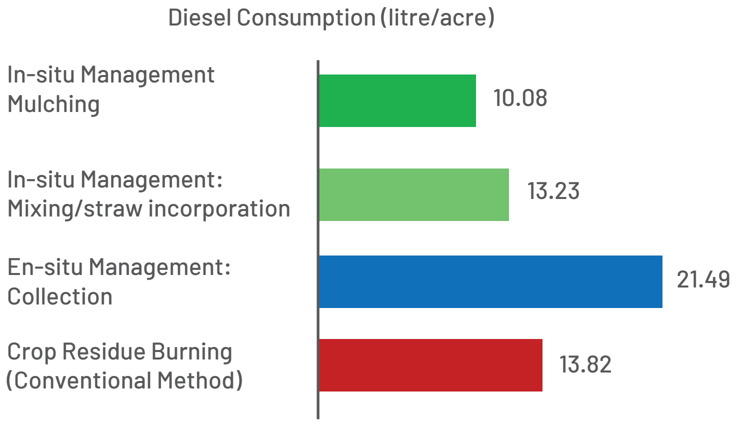
Farm inputs scenario, which is also driven by farmers' perception, is rapidly evolving with adoption of new practices. This demands life cycle cost of CRB vis-a-vis improved CRM practices to understand and inform farmers better towards ensuring long-term sustainability of improved CRM practices. Understanding full life cycle impacts of crop residue management will entail measuring change in agronomy practices across crops or seasons as opposed to existing framework where changes in the subsequent crop cycle (Rabi) are measured as a result of in-situ management of post-harvest remains of previous crop cycle (Kharif).

4.2.4 Fuel Savings

The primary data from farmers indicates that on-site diesel emissions from the use of farm tools are significantly lower in the case of in-situ management practices- mulching and straw incorporation, which were adopted on 75% of intervened land or 1,57,924 acres of agricultural area under rice. This is due to the fact that multiple tools and field runs (extensive tillage) are required under conventional (burning) methods when compared to conservation tillage system e.g., mulching with happyseeder.Based on the primary data from farmers on tools adopted and fuel usage, practice-wise as well as method-wise average fuel consumption in 172 villages. Practice-wise average fuel consumption is further plotted in Figure 17.

Fuel consumption is found to be significantly lower (-27%) for mulching than the conventional practice. Similarly, the straw incorporation the most preferred method for in-situ management in region consumes lesser fuel (-4%) compared to CRB. On average, the fuel savings across plots under in-situ management practices are observed to be 6.4% in 2020.These savings have come down from 23% in 2019 assessment of 102 villages to 6.4% in 2020 due to higher adoption of new tool superseeder which is more energy intensive compared to all other tools e.g. diesel consumption for superseeder is 14.26 litre/acre as compared to 7.25 litre/acre for happyseeder or 8.1 litre/acre for rotavator (See Annexure 4 for more details). In case of ex-situ management or baling, which is heavily mechanised intervention promoted primarily in communities where feasibility of in-situ options remains limited, fuel consumption is twice compared to mulching and 1.5 times the conventional practice or crop residue burning. Using diesel/fuel consumption as proxy for cost and emissions, same conclusion can be drawn for fuel cost and on site diesel emissions from agricultural equipment i.e. 6.4% lower fuel cost for farm operations covering biomass management and associated diesel emissions.

Figure 17: Average fuel consumption across different straw management practices



Source: CII Cleaner Air Better Life (2022) analysis

4.2.5 Cultivation Cost Savings

The cost of "field preparation and sowing the next crop" which includes straw management is a key factor that determines farmer's choice of CRM method. These operations take place in a limited time window spanning 2-3 weeks and it is not affordable for farmers to individually buy or own these tools. Many farmers seek direct support or short-term credits from farmer groups to avail services such as tractors, farm implements, seed drills etc. while harvesting or sowing crops. The CRM programme therefore created pool of necessary tools (as identified with participating farmers in the village-level meetings) with the Farmer Groups, Farmer Corporative Societies and Farmer Producer Organisations, who then mobilise these tools to farmers in designated villages.

Total 497 implements or farm tools have been handed over by CII Foundation to Farmers groups in last three years of programme implementation across 172 assessed villages. Farmer groups typically charge rentals tariffs to farmers which are lower than the market price and funds are utilised by farmer groups for maintenance of the tools/tool banks. Field data shows that in-situ management tools/implements distributed by farmer groups in intervened areas costed farmers 10-20% lower than the tariffs charged by private service provider.

Primary data collected from farmers in 172 intervened villages of Punjab and Haryana on tools rents, field capacities, fuel consumption etc. (See Annexure 2) were further utilised for cost analysis which helps us understand farmers' perspective and cost dynamics guiding farmers' decision to shift to sustainable agricultural practice. Depending on the tool combination utilised by farmer (See Table 3 for all major tool combinations in intervened areas), total cost of these operations consists of

1) cost of renting equipment (implements and tractor),

2) fuel cost and

3) labour inputs for these operations.

As harvesting rice is the common across all methods, cost for harvesting rice (combine harvester cost) has been dropped to build these cost comparisons. Only the additional expenditure of attaching a Super Straw Management System (Super SMS) during harvesting rice are considered. These additional expenditures are- cost of attaching/renting Super SMS, incremental fuel consumption, and more time taken for operation or lower field capacity as a result. This overall cost figure is referred as the cost of crop residue management.

Key results of above-described cost analysis are plotted in the Figure 18. 'Intervention group' refer to intervened farmers who accessed tools through shared-economy model created with farmer groups and it is part of 85% farmers who did not burn rice straw in CII intervened areas of Punjab as well as Haryana in 2020. Whereas the 'standard group' refers to farmers who rent tools from private agencies or other farmers and represents the farmers outside intervention area. Key results of cost analysis can be summarised as below-

- Conventional practice of Crop Residue Burning (CRB) costs farmer INR 2860 per acre on average. The cost of in-situ management methods is comparable to CRB benchmark, especially so for intervened farmers. Also, mulching is found to be the most cost-effective method which costs farmers 2.3% lesser than the conventional method.

- Cost benefit is significantly for intervention group who avail tools from farmer groups compared to the standard group who avail them from private service providers. In other words, in-situ management costed intervened farmers on average 13.3% less when compared to other areas without any active intervention.

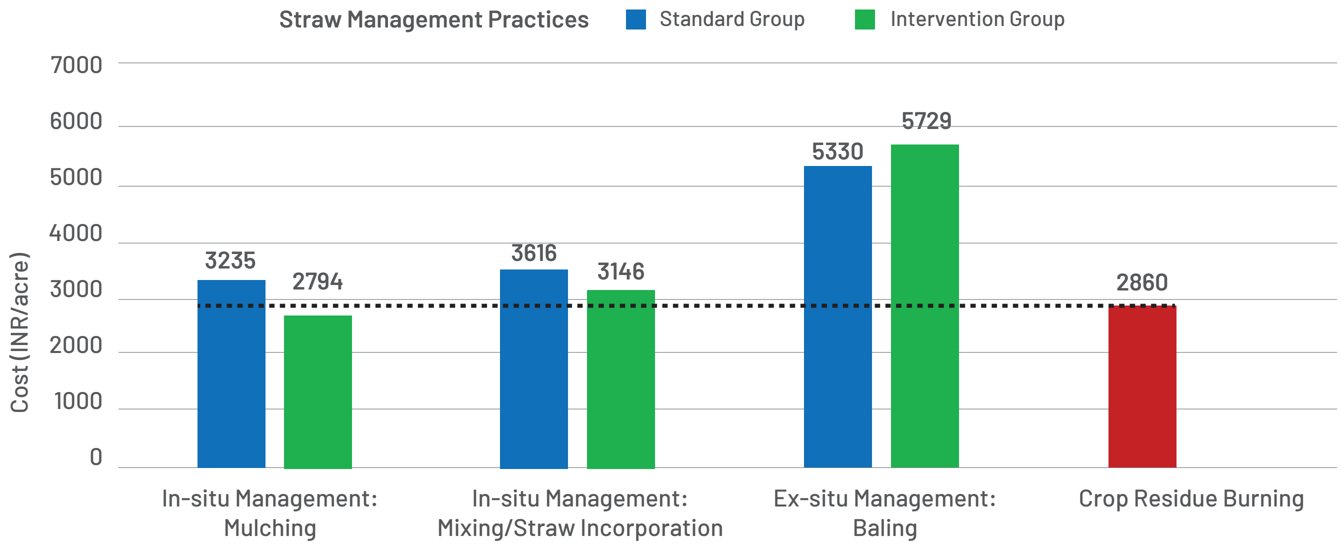
- For standard group across two North Western states, in-situ costs 13-26% more compared to CRB. This indicates that there is a definite room for improvement in delivery of Central Sector Scheme to promote in-situ technologies.

- The cost of in-situ management: straw incorporation is observed to be relatively higher in the year 2020 due to large scale adoption of new tool superseeder. Cost of straw incorporation is found to be 10% higher than CRB due to higher fuel consumption associated with superseeder. Farmers still prefer superseeder due to convenience as single tool run is sufficient to incorporate straw with superseeder as opposed to rotavator which takes multiple tool runs (2-3) to effectively incorporate straw in the field.

- Under standard group, ex-situ baling costs almost double than the cost CRB. Despite intervention, ex-situ management still costs roughly the double when compared to the CRB benchmark. Scaling ex-situ solutions therefore requires significant intervention to exploit economy-wide circularities and bridge the gap between in-situ crop residue management solutions and air pollution. Also, baling is energy intensive and as a result, baling cost have been significantly affected, 17% higher from 2019, due to increase in fuel prices.

Compared to last years study the cost of cultivation (refer Annexure 5) for standard group for adopting different CRM practices have marginally increase 2% for mulching, 13% for Straw incorporation and 17% for ex-situ, the two major reasons are first rise of fuel prices over the year and second the change in farmer adoption of different tool combinations. Among tractor, labour and fuel cost, fuel cost been the most immediate expanse it will influence the farmers choice the most. Slight decrease of 3% in cost with adopting crop residue burning is on account of fincreased adoption of less fuel consuming tool combination. There is significant increase 13% in cost of adoption of mixing/straw incorporation owing to a greater number of farmers opting to utilise less fuel efficient superseeder for managing straw.

Figure 18: Estimated cost of cultivation across management practice



Source: CII Cleaner Air Better Life (2022) analysis

4.3 Environmental Impacts

Key environmental impacts captured by study include:

- **Ambient Air Quality benefits including avoided particulate matter and secondary aerosols contributing to air pollution**
- **Climate Benefits: mitigationof non-CO_2 greenhouse gases and Black Carbon**
- **Soil Health Benefits with sequestration of soil organic carbon**
- **Water Conservation due to reduced irrigation requirement**

4.3.1 Ambient Air Quality Benefits

Crop residue burning severely impact the local air quality affecting the heath of rural population and adding to public health expenditure. Living in a district with intense agricultural burning (experienced in two intervened districts) is associated with three-fold increase in acute respiratory infections (Chakrabarti et al 2019). From environment and health perspective, fine particulate matter (with size below 2.5 μm or $PM_{2.5}$) emissions are most critical in terms of their health impacts (WHO 2019) and can travel to far away distances (in a matter of few days to weeks) causing environmental and health impacts at local, regional and global scales, fine particles less than 2.5 microns ($PM_{2.5}$) pose the greatest risks to health, as they are capable of penetrating peoples' lungs and entering their bloodstream.

Among gaseous pollutants, familiar Volatile Organic Compounds (VOCs) include benzene, formaldehyde, toluene etc., many being toxic and carcinogenic (ALA 2019).

VOCs are highly reactive gases which quickly react and form secondary particles in atmosphere with size ranging from fine to ultrafine. Hence, from health perspective, they are very important pollutant category to be addressed. Pollutants with the strongest evidence for public health concern include particulate matter (PM), ozone (O_3), nitrogen dioxide (NO_2) and sulphur dioxide (SO_2) (WHO 2019) and they also considered as criteria pollutants regulated under India's National Ambient Air Quality Standards (NAAQS) (CPCB 2014). NAAQS additionally considers Ammonia for control under air quality regulations. Ozone is also classified as criteria pollutant under NAAQS for air quality regulation and causes breathing problems, triggers asthma and reduces lung function, causing lung diseases. Ground-level ozone is produced when carbon monoxide (CO), methane, or other volatile organic compounds (VOCs) are oxidised in the presence of nitrogen oxides (NOx) and sunlight (WHO 2019).

Using a conservative estimate of 2.5 tonne rice straw generation per acre, based on quantification of survey data (with confidence level of +/- 2.03%) adoption of burning is restricted to 13% (figure 19) of entire intervened farmland across 172 villages which amounts to 340 thousand tonne rice straw avoided from being burned. Based on literature it is also estimated that from a paddy field spanning an acre, approximately 2.5-4.77 tonne rice straw is generated in Punjab (Kumar et al 2015). Based on emission factors for rice straw burning from various sources as compiled and listed in Shrestha et al 2012 and Singh et al 2020, average emission factors were applied for understanding the avoided emissions as a result of project activities. These emission factors and avoided emissions are listed in the Table 5 and are calculated assuming 'dry matter to crop residue ratio' of 0.85 and 'burning efficiency ratio' of 0.87.

Living in a district with intense agricultural burning (experienced in two intervened districts) is associated with three-fold increase in acute respiratory infections (Chakrabarti et al 2019).

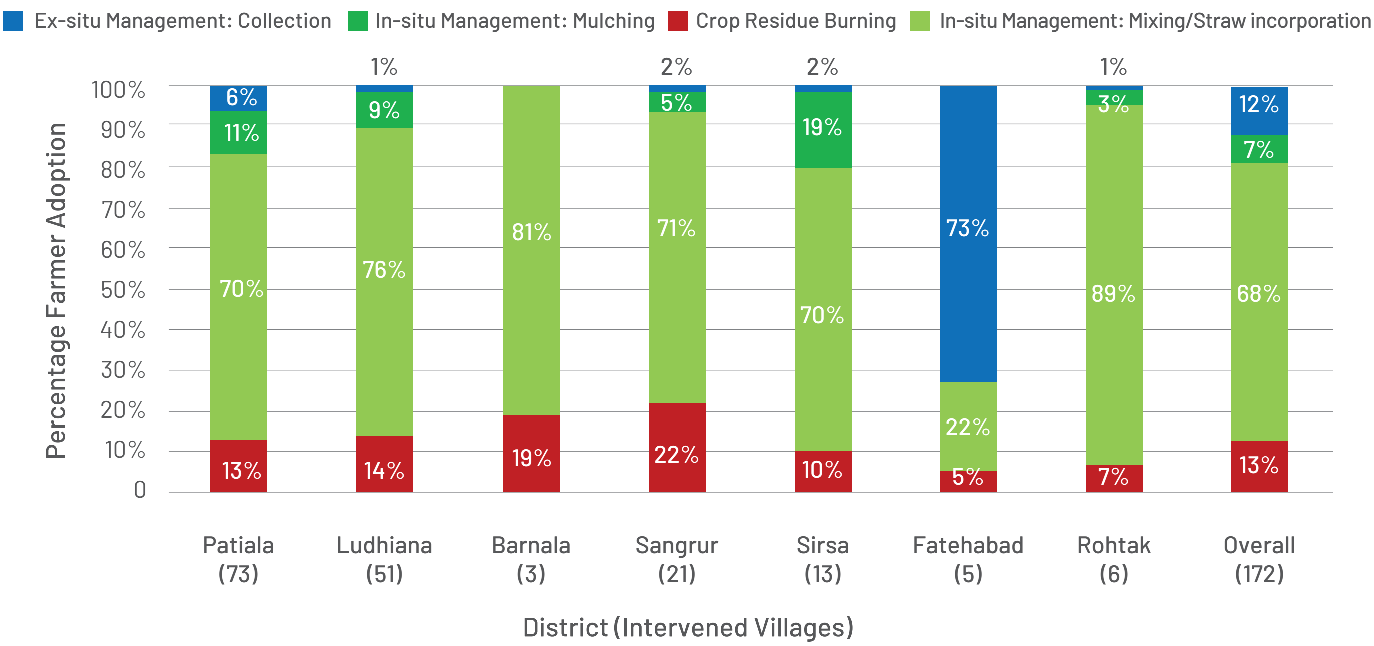
Table 5: Major pollutants and emission factors for biomass burning

Pollutants	Emission Factors [g/kgdrymass rice straw]	Avoided Emissions in 2020-21 [tonne]
Particulate matter emissions:		
PM	9.64	2421
PM_{10}	6.30	1582
$PM_{2.5}$	5.75	1444
BC	0.64	161
OC	2.20	552
Gas Emissions:		
CO_2	1220.32	306442
CO	101.29	25436
CH_4	9.60	2411
VOC	7.00	1758
NH_3	4.10	1030
N_2O	0.48	121
NO_x	2.28	573
SO_2	0.29	73

Source: CII Cleaner Air Better Life (2022) analysis

It is estimated that primary particulate matter emissions worth 1.6 thousand tonnes of suspended particulate matter (PM_{10}) are avoided. Avoided primary particles included total 1.4 thousand tonne fine particulate matter ($PM_{2.5}$) emissions. Besides primary particles, gaseous pollutants (VOCs, SOx, NOx, NH_3) amounting 3.4 thousand tonnes secondary aerosols in total, with potential to travel across the region and lead to secondary particle pollution, are also avoided.

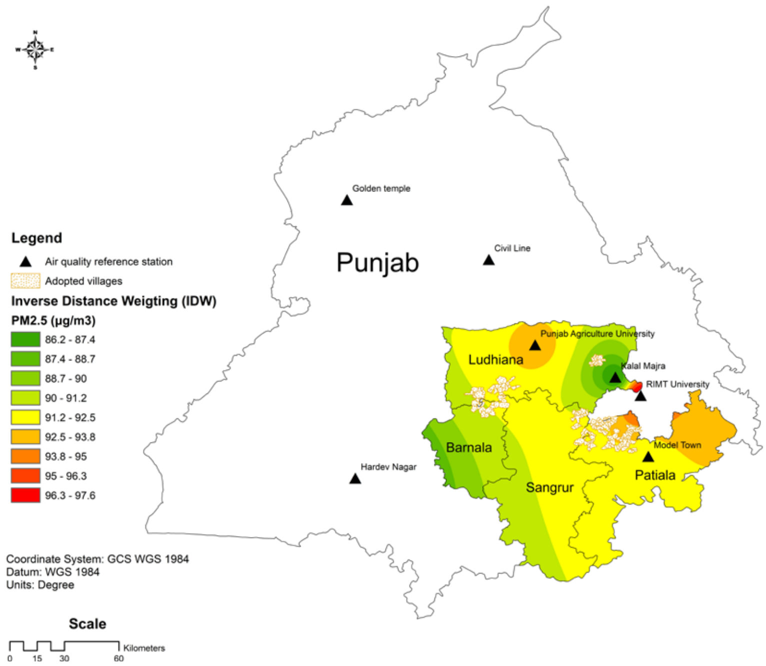
Figure 19: Adoption of crop residue management technique across Districts (Intervened Villages)



Source: CII Cleaner Air Better Life (2022) analysis

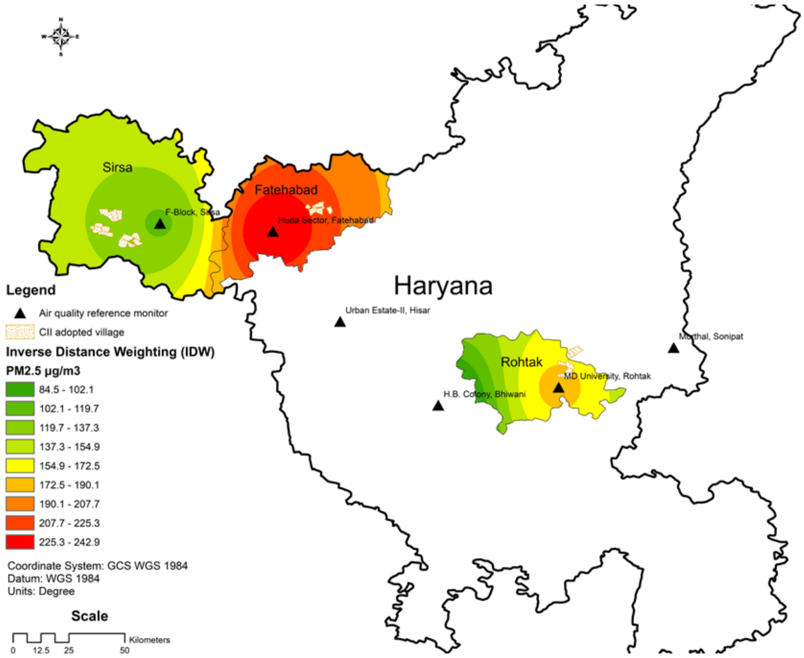
Figures 20 and 21 summarises the air quality situation from 1 November 2020 to 31 November 2020 in the peak season in intervened districts based on $PM_{2.5}$ concentrations from reference grade monitoring stations in Punjab and Haryana. The map is generated using the 'inverse distance weighted' interpolation technique where cell values are estimated by averaging the values of sample data points from reference grade stations (six in Haryana and seven in Punjab) in the neighbourhood of each intervened locations. While exceptionally high $PM_{2.5}$ concentrations are recorded in these rural locations of Punjab and Haryana in the range of 85-97 µg/m3and 81-242 µg/m3 respectively, figures also indicate better air quality scenario in intervened villages in general compared to those outside CII intervention. Also, the air quality effect is more pronounced in Haryana geographies compared to Punjab due to predominantly North-Western wind directions in the season. It is worth noting that it is difficult to quantify the air quality impact of interventions in specific geographies due to transboundary nature of air pollution and dynamic change with external (weather) factors. Therefore, building combination of approaches using remote sensing, infrared imaging, climatology and sensor-based monitors, field verifications etc. is a future endeavour to be able to disentangle emissions originating inside and outside an intervened village or cluster.

Figure 20: Air quality situation across intervened districts in Punjab geographies from 01 Nov 2020 to 31 Nov 2020 on the basis of data from reference grade stations deployed by Punjab Pollution Control Board



Source: CII Cleaner Air Better Life analysis of CPCB (2021) data November 2020

Figure 21: Air quality situation across intervened districts in Haryana geographies from 01 Nov 2020 to 31 Nov 2020 on the basis of data from reference grade stations deployed by Haryana State Pollution Control Board



Source: CII - Cleaner Air Better Life Analysis of CPCB (2021) Data, November 2020

4.3.2 Climate Mitigation

Burning of straw also impact the global climate with release of Green House Gases (GHGs). These include BC, VOCs, CO and CH_4 although there is both warming and cooling impact due to variety of feedback mechanisms, also NOx can lead to both warming and cooling. Here only climate pollutants with net global warming impacts (i.e. CO_2 and CH_4) were considered for estimating climate impacts of farm interventions. Using 100-years Global Warming Potentials (GWPs) for emitted greenhouse gases which contribute directly to global warming, it is estimated that approximately 378.24 kilo tonnes CO_2e of direct global warming impacts were averted. Considering renewable nature of biomass and as a result only non-CO_2 emission mitigation from avoided burning of biomass, GHG emission worth 68 Kilo tonnes CO_2e mitigated due to CII's intervention in Punjab and Haryana.

Black carbon (BC) emissions, which again form a part of $PM_{2.5}$ emissions, are Short-Lived Climate Pollutants (SCLPs) and cause radiative forcing. Despite its short atmospheric lifetime, BC is one of the largest contributors to global warming after CO_2. It also known to decrease agricultural yields and accelerate glacier melting (Myhre et al 2013, WHO 2019). Estimated 162 tonnes of Black Carbon (BC) were avoided as part particulate matter emissions in $PM_{2.5}$ range.

GHG emission worth 68 Kilo tonnes CO_2e mitigated due to CII's intervention in Punjab and Haryana

4.3.3 Healthier Soil and Carbon Sequestration

Crop residue burning leaves topsoil devoid of beneficial soil organisms and micro-organisms (e.g. earthworms, bacteria, fungi, algae, actinomycetes, nematodes etc.) which play a crucial role in keeping the soil healthy. This key factor combined with mono- cropping pattern (rice-wheat monoculture with no nitrogen fixing plants or legume crops) prevalent in the region leads to higher dependence on inorganic fertiliser chemical inputs and poor soil health resulting into lower productivity from agriculture in the long-run. Various ecosystem services lent by beneficial topsoil organisms which are essential to good soil health include- carbon transformations, maintenance of nutrient cycles, soil structure maintenance, and the regulation of pests and diseases (Kibble white et al 2007).

Enhanced crop yield and lower dependence on chemicals inputs together serve as good proxy for assessing overall soil health improvement in intervened geographies. As described in the Section 4.2, farmers are experiencing enhanced yield benefits from adoption of in-situ management practices while being able to lower the dependence on chemical inputs at the same time. It is worth noting that historically soil assessments have been focused on crop production, but, today, soil health also includes the role of soil in water quality, climate change and human health (Lehmann et al 2020).

Key activities promoted with intervened farmers and adopted by farmers at community-scale, which include retention or application of crop residue and reduced tillage (or topsoil disturbances), improved overall soil health which is fundamental to many Sustainable Development Goals. Ecosystem services lent by improved crop residue management and healthier soil as a result into improved livelihood and resilience of farming communities. Sustainable agricultural practices, including mulching and straw incorporation, lead to sustained improvement in yield as well as quality of produce.

While the nutrients required for crop growth-Phosphorus, Potassium, Nitrogen and Sulphur are lost partially by 25%, 20%, 90% and 60% respectively due to burning of rice straw, it is estimated that 100% of organic carbon gets lost in the process (Kumar et al 2019). Accompanying loss of carbon is estimated to be 0.97 tonne Carbon per acre from burning of rice straw. Soils in the Indo-Gangetic Plains are severely degraded in soil organic carbon (SOC) content estimated at or below 0.1% which has implications on environmental quality, and food security (Paroda et al 2018). An increase in soil organic carbon increases bacteria and fungi in the soil and studies reveal that soil treated with crop residues held 5–10 times more aerobic bacteria and 1.5–11 times more fungi than soil from which residues were either burnt or removed. Ten years of continuous crop residue addition with minimum to zero-till is linked to 17-25% higher SOC compared to conventional tillage practices (Lohan et al 2017). As described in earlier sections, interventions in 2020 led to recycling of 319 thousand tonnes of biomass back into soil. Out of total biomass returned to the field, 90% was incorporated into the soil while roughly 10% was retained as mulch layer in the field. This implies that estimated 1.24 Lakh tonnes of soil carbon sequestered across CII areas within one year in 2020. While this amount of carbon is sequestered in soil, long-term sequestration of carbon may need validation with field measurements using scientifically approved methodologies.

4.3.4 Water Conservation

Irrigation water savings are especially relevant as replenishment rate of ground water in two North Western States is well below the withdrawal rate and many districts have experienced a decline in the water table of over 0.50 meters per year reaching critical levels (Paroda et al 2018). Addition of organic matter to soil, as part of the intervention, helps greatly in conserving this water. Water savings in intervened area are calculated on the basis of correlation developed from synthesis of scientific literature and validated from the field: during FDG with farmers. Estimating water savings requires good approximation of total quantum of irrigation water which in turn depends on- (1) number of irrigation cycles and (2) water application per cycle which is typically measured in terms of the height of water column.

Usually, 3-4 irrigation cycles[7] are applied over wheat growth period depending on weather or irrigation schedule in according with the soil moisture status. Field data as well as scientific literature suggests that pre-sowing irrigation water requirement for wheat crop, which is 75-100 mm, is eliminated in the fields mulched with rice straw (Sidhu et al 2015, Singh et al 2018). Rice straw application further reduces this water requirement by 35-45 mm due to reduced soil moisture loss through evaporation and 5-10% increase in water holding capacity (Lohan et al 2017; Sidhu et al 2015; Singh et al 2011). Accordingly, we used two conservative factors adopted for water savings are -

- Water savings equivalent to 75 mm water column per season owing to avoided pre-sowing irrigation only in the mulched fields.
- Water savings equivalent to 40 mm water column during the wheat crop growth in fields where rice straw is retained in field from mulching and soil incorporation.

Evidence from field suggested 13% savings (Sharma et al 2020) in total water requirement during crop growth phase on average across project geographies across fields where rice straw is applied in-situ. The information on consumptions of water in every cycle varies and is not captured in the field data which limits its direct use to estimating actual water savings. Electricity can serve as a good approximation for water consumption per cycle in consumption majority of areas irrigated with groundwater, but farmers usually do not keep track of electricity consumption for groundwater extraction due to electricity being subsidised and free for agriculture in agrarian states of Punjab and Haryana.

Using strong field evidence and adapted factors from literature as described above, our analysis estimates that 24.8 billion litres of water savings (See Table 6 for state-wise information) are achieved in intervened geographies as a result of large-scale adoption of in-situ crop residue management practices. Net benefit of enhanced water use efficiency is observed to be much higher- water-use efficiency improves by 25% in wheat crop due to retention of rice straw as mulch. In the long-term as soil organic content goes up with the application of biomass which helps in improving the soil structure and further reducing the run-off water as well as waterlogging issue faced by farmers in Haryana.

Table 6: Water saving across states with addition of organic matter to soil

Water Saving	Punjab [million litres]	Haryana [million litres]
Pre-sowing savings	3,318.24	854.44
Savings during plant growth	17,030.37	3,582.56
	Total Water Saving	**24,785.60**

Source: CII Cleaner Air Better Life (2022) analysis

[7] Depending on the prevalent weather in a year

To summarise the environmental impacts, interventions in 2020 resulted in avoidance of total 340 thousand tonnes of rice straw from burning.

- **1.6 thousand tonnes of PM10**
- **1.46 thousand tonnes PM2.5**
- **3.4 thousand tonnes of gases pollutants (SOx, NOx, VOCs and NH3)**
- **4.1 lakh tonnes of CO2e GHGs (3.1 lakh tonnes CO2e CO2- GHGs, 1 lakh tonnes CO2e non-CO2-GHGs)**
- **161 tonnes Black Carbon**
- **1.24 lakh tonnes carbon sequestered by recycling of 319 thousand tonnes of organic matter**
- **Total water saving worth 25 billion liters**

Overall, interventions in last three years resulted in avoidance of total 549 thousand tonnes of rice straw from burning.

- **2.6 thousand tonnes of PM10**
- **2.3 thousand tonnes PM2.5**
- **5.6 thousand tonnes of gases pollutants (SOx, NOx, VOCs and NH3)**
- **6.65 lakh tonnes of CO2e GHGs (5 lakh tonnes CO2e CO2- GHGs, 1.6 lkh tonnes CO2e non-CO2-GHGs)**
- **260 tonnes Black Carbon**
- **1.96 lakh tonnes carbon sequestered by recycling of 0.5 million tonnes of organic matter**
- **Total water saving worth 37.65 billion liters**

Interventions in last three years resulted in avoidance of total 549 thousand tonnes of rice straw from burning.

5. Key Learnings from the Field

Farmers groups including farmer cooperative societies (FCSs) and Farmer Producer Organisations (FPOs) can be leveraged to fill the existing gap on ground and provide these services to farmers on shared basis.

Key lessons or learning from three years of CII CRM work with farmers are summarised as below:

- Availability and affordability of agricultural tools, which are needed by farmers only in fifteen days in a year, are extremely important enablers on the ground. Farmers groups including farmer cooperative societies (FCSs) and Farmer Producer Organisations (FPOs) can be leveraged to fill the existing gap on ground and provide these services to farmers on shared basis. Role of FCSs is especially crucial for agriculture in the region as they often provide short-term credit linkages to small-medium farmers for key agricultural activities through the year.

- One size does not fit all. Therefore, local-level participatory planning with rural communities while considering of specific contextual factors such as crop cycle, crop varieties, soil types etc. plays a crucial role in planning shared-infrastructure which suits the local needs. Even in CII Intervened areas 12 major tool combinations are preferred by farmers which are documented in this study, farmers choice is influenced by numerous factors but generally, theypick options with least fuel consumption until other option is convenient and less time consuming.

- In-situ management tools were accessed by farmers the most (77% of all farmers) though shared-economy model created by CII with farmer groups (FCSs and FPOs) and these include- Mulcher at 94%, MB Plough 98%, Superseeder 73% and happyseeder (HS) at 58%. The penetration of HS has significantly improved due to GoI subsidy scheme and surveyed data shows that 26% farmers used self-owned HSs. Penetration of other needed and less prevalent tools can be prioritised basis such information derived from farmer surveys.

- Partial burning, which is a hybrid practice of burning 30-40% of heaped crop residue and incorporation remaining into the soil, continued at significant pace in last 2-3 years due to technical feasibility issues on the ground to utilise 100% rice straw towards in-situ application. It has come down substantially in 2020-21 due to widespread use and success of superseeder in the region.

- Superseeder, a tool for enabling straw incorporation and sowing next crop, has emergedas the most preferred tool for in-situ management in 2020-21. While superseeder with superior straw mixing capability, which address the 100% in-situ management challenge with other tools as described above, is fast replacing the use of rotavator in in-situ management method: straw incorporation; it requires high horsepower (greater than 55HP) tractor which is a limiting factor for most marginal-small farmers. Although high horsepower tractors were rented by CII Foundation to support farmers, it remains key concern as numbers of such tractors are limited in States. Focused group discussion with farmers highlighted that the use of superseeder is constrained in low-laying area and hard soil few farmers from Sirsa clusters faced issues while sowing and thus preferred mulching over this. Nonetheless, it is found that partial burning incidents came down heavily across different size classes from 34-35% in 2019 to 4-9% in 2020 due to large-scale adoptions of superseeder in 2020-21.

- Farmer adoption also improved, marginally, in favour of less fuel and time-consuming practice of mulching. There are underlying concerns based on past experiences and perception which hinder most fruitful decision making. Despite farmer apprehension to adopt happyseeder in new areas, those who have adopted mulching and continue to

use happyseeder are deriving more yield benefits on average from mulching at 7% higher yield on average compared to conventional practice involving crop residue burning. In addition, there are significantly higher environmental merits associated with mulching as documented by this study. Mulching provides the highest yield to farmers with up to 10% higher yield recorded after 3 years. Straw incorporation showed comparable yield benefit at 6% in 2020-21 but mulching yields much better results over straw incorporation with consistent increase in yield with sustained adoption. Group Discussion with farmers also gave insights on other important co-benefits of mulching linked to climate adaptation and resilience. Anecdotal evidences were collected from farmers on cropssown using zero tillage technique being more resilient to extreme weather evens such as- heavy winds, hailstorms etc.

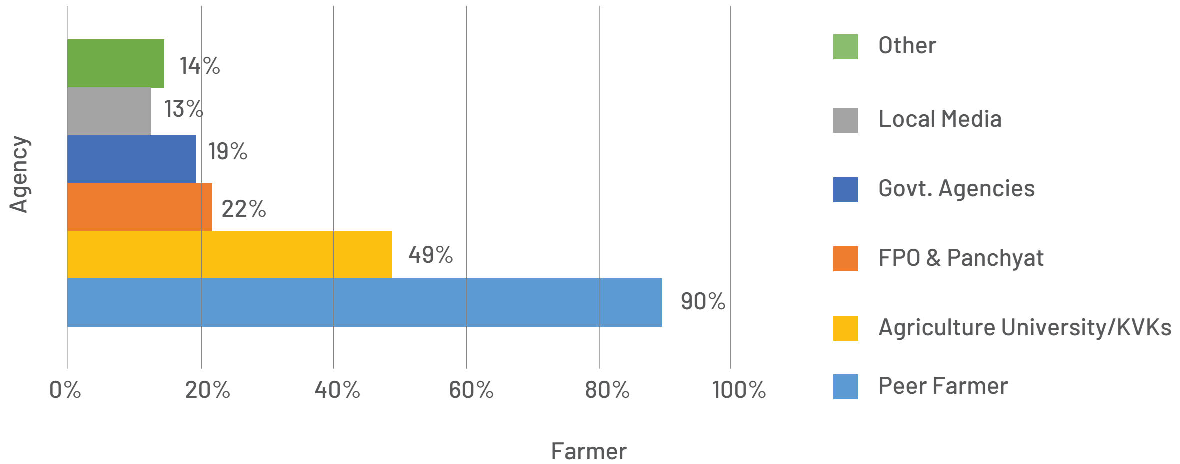
At this critical conjecture of technology adoption in the region, it is important that diversified technology options are available to farmers with clear information on costs, benefits, and associated risks. There is a clear need of dedicated information campaigns based on field data to rectify farmers perceptions around mulching.

It is worth noting that similar developments or upgradation with happyseeder are required to promote mulching. Upgraded version of HS which is Smart seeder was recently introduced and underwent trails in 2021-22. Its performance and farmers' feedback need to be better gauzed in coming year as positive development with smart seeder may truly unlock potential of mulching and zero tillage method with most environmental merits for the NW region.

- The paddy varieties also impact the farmers overall choice of practice. Significant number of farmers in Haryana (Fatehabad and Rohtak) who opted for shorter duration varieties of rice PB-1509 are found to be more likely to move towards sustainable practices as straw management becomes easier due to comparatively smaller amount of post-harvest crop remains. However, even in these cases, proper awareness and capacity building is required to move away for conventional practices.
- The overall growth rate in adoption fell from 83% in 2019 to 77% in 2020. This expected due to impacts of COVID19 which caused manpower shortages for farmers across NW states.
- As documented in the report figure 22, the peer-to-peer learning and augmentation of extension services in rural areas is the best way forward for raising farmers capacity and confidence on improved crop residue management techniques.

Majority of farmers, 90% of the surveyed farmers, believe their fellow farmers or peers with almost half of the farmers believing Scientists at State Agriculture Universities (SAUs) as well as Krishi Vigyan Kendras (KVKs). Significantly smaller number of Farmers trust any other agency or entity.

Figure 22: Sources of information preferred by farmers



Source: CII Cleaner Air Better Life (2022) analysis

CII CRM programme executed 12 diverse set of behaviour change and communication as well as training activities in intervened areas with estimated 10 meeting per villages per year involving of sections of local communities. Local leaders, farmer groups and progressive farmers were crucial to build trust with local communities.

- The data from ground from farmers adopting sustainable practices from past three years does not support farmer communities' perceptions of increased cost of farm input with adoption of sustainable practice. And thus, targeted awareness is needed to communicate the costs and benefits of different methods at community level by leveraging farmers from same community who have adopting sustainable practices from more than 5 years (vis-à-vis progressive farmer), who have experienced number of benefits from soil health improvement to crop yield. Also, the farm inputs scenario, which is rapidly evolving with adoption of new practices, is mainly driven by farmers' perceptions. This demands better understanding life cycle costs of CRB vis-a-vis improved CRM practices and communicating these to farmers to ensure long-term sustainability of improved CRM practices.

- Diverse economic benefits derived by participating farmer especially those who adopted in-situ management are described in detail in this report and form a strong basis for continued awareness and information to farmers across NW region. In-situ management resulted in lower fertiliser consumption at 4-6% in last three years whereas the fertiliser consumption went up for farmers continued with burning at 8-12%. Based on progressive farmers data this reduction is expected to come down by 24% in 5 years of adoption. However, it is worth noting that in the first year of adopting in-situ methods, fertiliser consumption may go slightly by 3-5% owing to nitrogen immobilisation and hence there is a strong need to communicate these risks to farmers adopting in-situ for the first time. Application of higher amounts (5% higher urea consumptions for baled fields) of inorganic inputs correlates with commensurate nutrients in the biomass baled-out of the field.

- Direct savings for weedicides are quantified to be -29% and -20% for mulching and straw incorporation respectively (compared to baseline/CRB which is INR 686 per acre). Besides higher benefits, mulching also shows consistent decline in weedicide consumption or cost from -20% for first year of adoption to -45% in three years.

- Fuel consumption is found to be on average 6.4% lower for in-situ management and up to 27% lower for mulching. Overall, the fuel savings have come down from 23% in 2019 assessment of 102 villages to 6.4% in 2020 due to higher adoption of new tool superseeder which is more energy intensive compared to all other tools e.g. diesel consumption for superseeder is 14.26 litre/acre as compared to 7.25 litre/acre for happyseeder or 8.1 litre/acre for rotavator.

It is found to surveyed data that tariffs charged by farmers groups, which were supported by CII, are 10-20% lower across agricultural tools compared to private service providers. Detailed modelling for cost of cultivation undertaken in this study shows that in-situ management practices costed intervened farmers on average 13.3% less when compared to other areas without any active intervention. The same cost figure is found to be much higher for areas without interventions in NW region, where in-situ management instead costs 13-26% more than conventional practice: CRB. This clearly shows the impact of shared-economy model created by CII in intervened areas. Another major finding on this front is regarding baling which is still not cost-effective (costing twice the cost of conventional method: CRB) for participating farmers due to higher upfront cost and recurring cost involved in operations and maintenance. Baling is also energy intensive and as a result, baling cost have been significantly affected, 17% higher from 2019, due to increase in fuel prices.

- There is need to boost solutions to farmers who cannot utilise rice straw in-situ i.e. farmers with alternate crop rotation (e.g. rice-vegetable-sunflower as opposed to predominant rice-wheat farmers). These farmers do not find in-situ management either cost-effective or productive for the next crop. Therefore, ex-situ as an important part of overall biomass management ecosystem, needs to be made more cost-effective or affordable to farmers. While these farmers find it easier to burn in absence of any cost-effective alternate, often they are also proactive in clearing the fields manually if they are able to find value in crop residue through use in composting, animal fodder etc. Multiple solutions therefore need to be explored and deployed for meetings the needs of all farmers in future.

Targeted awareness is needed to communicate the costs and benefits of different methods at community level by leveraging farmers from same community who have adopting sustainable practices from more than 5 years.

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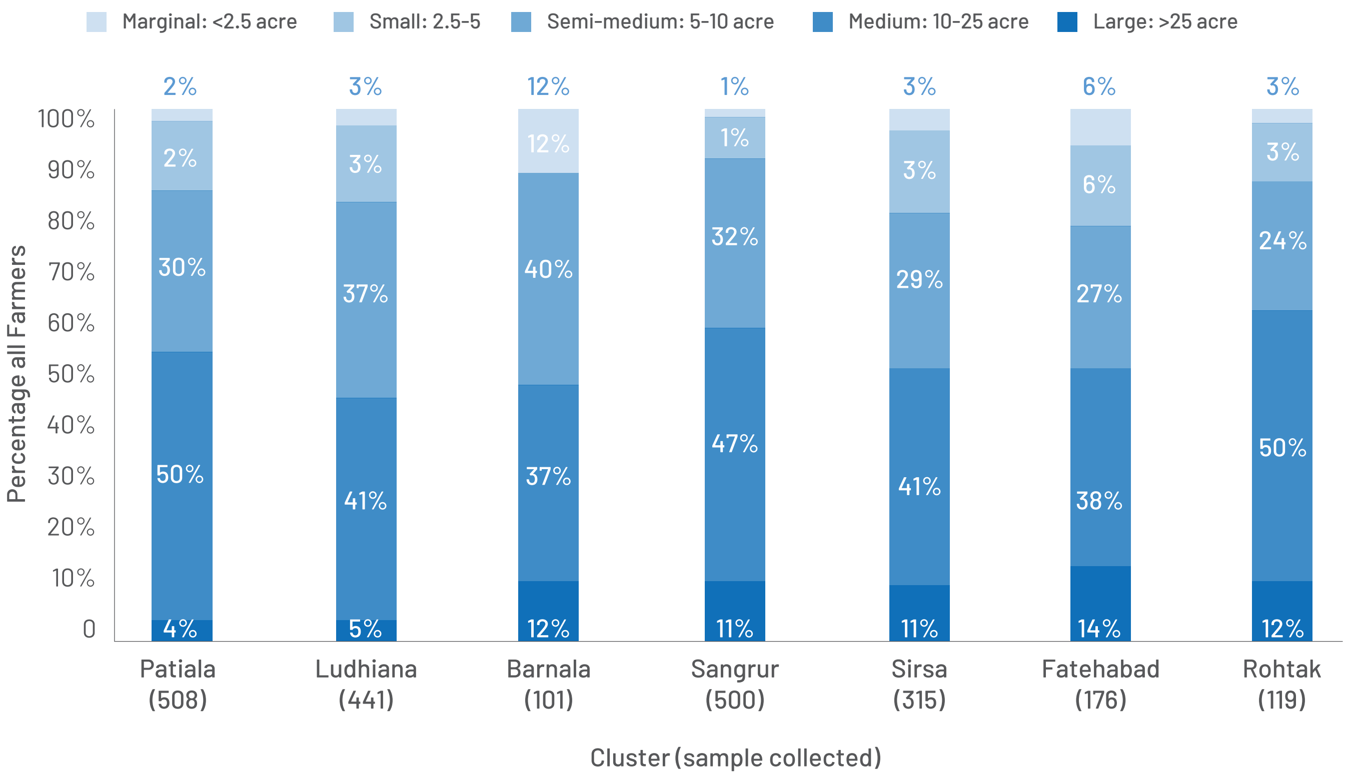
Annexure 1

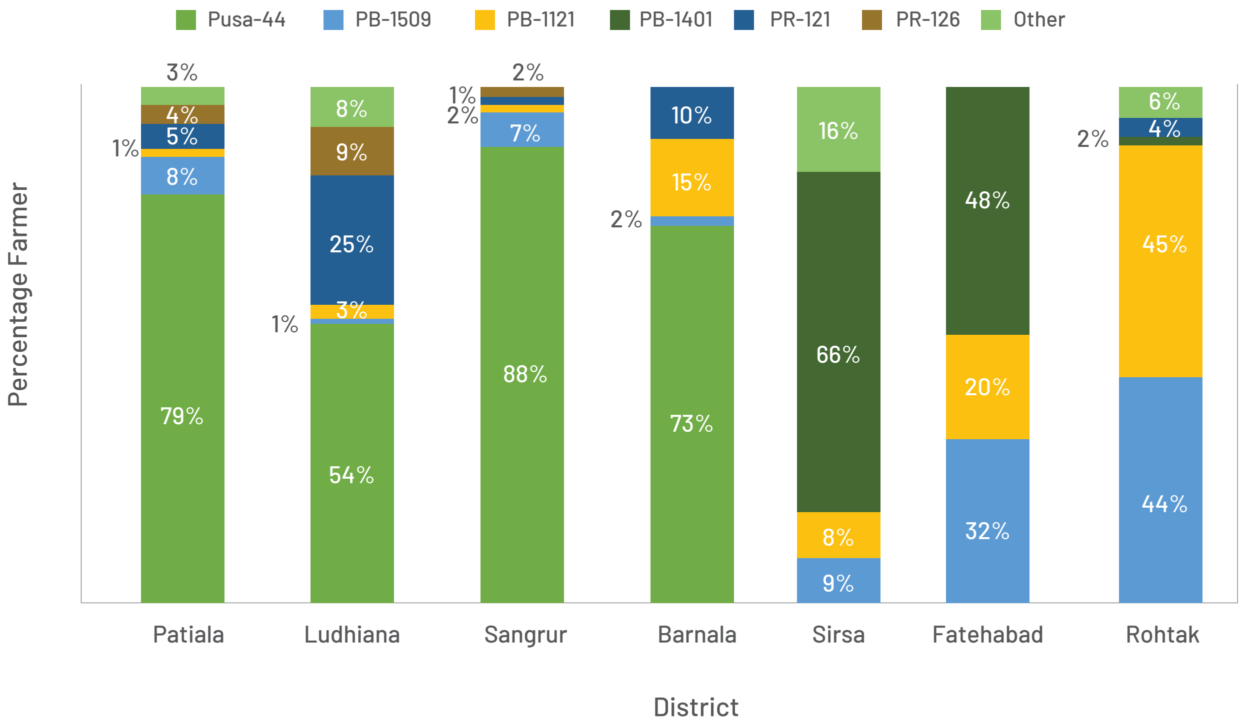
Farmer sample distribution across districts



Source: CII Cleaner Air Better Life (2022) analysis

Annexure 2

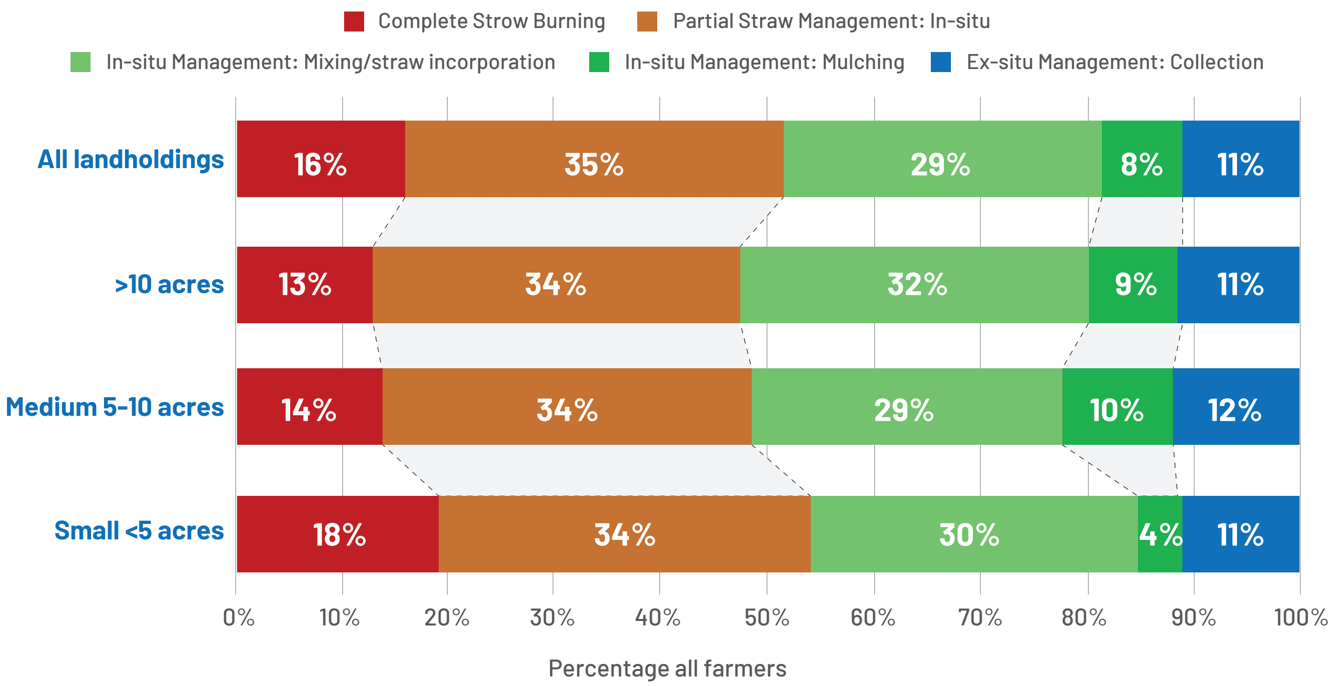
Paddy variety sown in intervened area



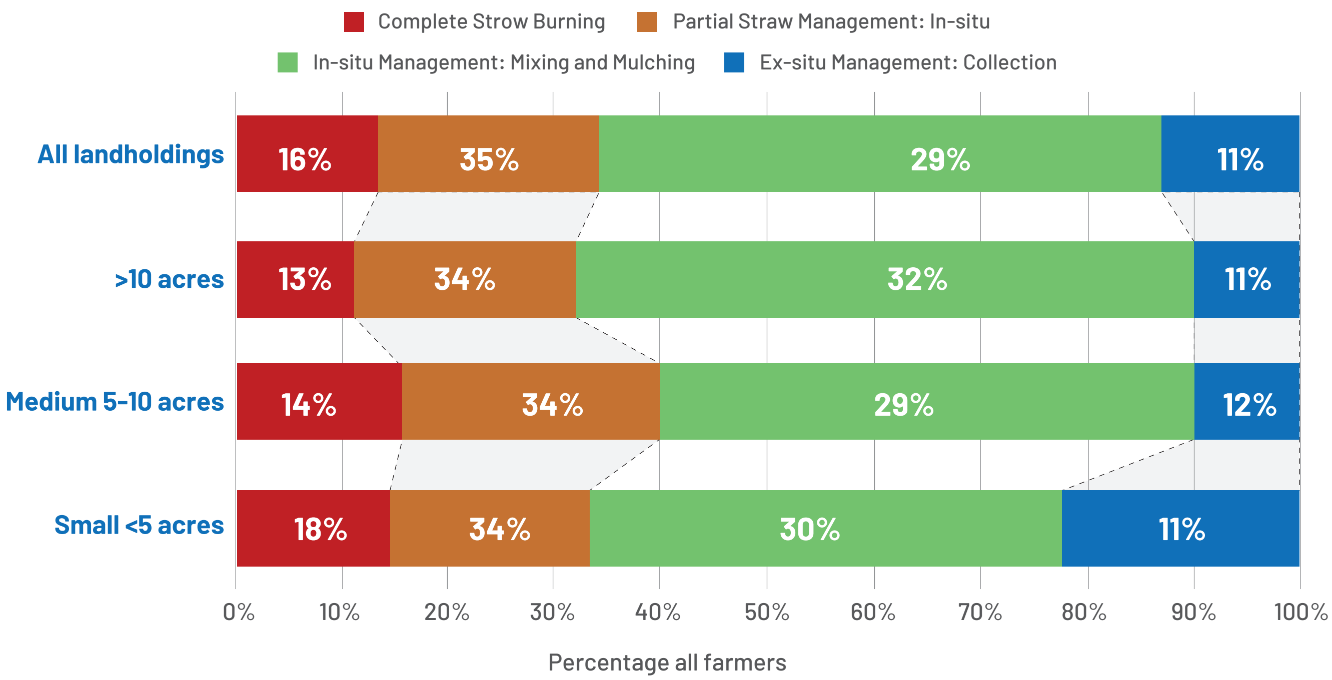
Source: CII Cleaner Air Better Life (2022) analysis

Annexure 3

Adoption of straw management practices across land holding size classes in intervention year 2018 and 2019



Source: CII Cleaner Air Better Life (2022) analysis



Source: CII Cleaner Air Better Life (2022) analysis

Annexure 4

Details of agricultural tools used by intervened farmers

Tool	Field capacity[1]	Weight[2]	Tractor Power[3]	Diesel consumption[1]	Rent[1]	
					Private Agency	Farmer Group
Tool name	**acre/hour**	**kg**	**horsepower**	**litre/acre**	**INR/acre**	**INR/acre**
Combine Harvester (CH)	2.40	...	...	9.00	1175	.....
CH with SMS	1.53	...	≥75	13.50	1552	.....
Mulcher	0.58	585	≥ 50	8.00	2377	2063
Cutter-cum- spreader	3.00	300	30-40	3.00	591	471
Reversible Mould Board Plough	0.44	450	> 50	8.63	3067	2547
Harrow Disk	2.00	480	40	4.00	551	472
Cultivator	2.38	350	40	4.00	523	448
Land Leveller	2.38	350	40	4.00	523	448
Zero Till Seed Drill	0.60	350	30	4.59	1089	901
happyseeder	0.53	710	≥ 50	7.25	2480	2134
Rotavator SD	0.55	550	50	8.07	2375	2142
Superseeder	0.43	1122	>55	14.26	3416	2912
Baler+Raker	0.59	...	>50	12.46	2631	2564

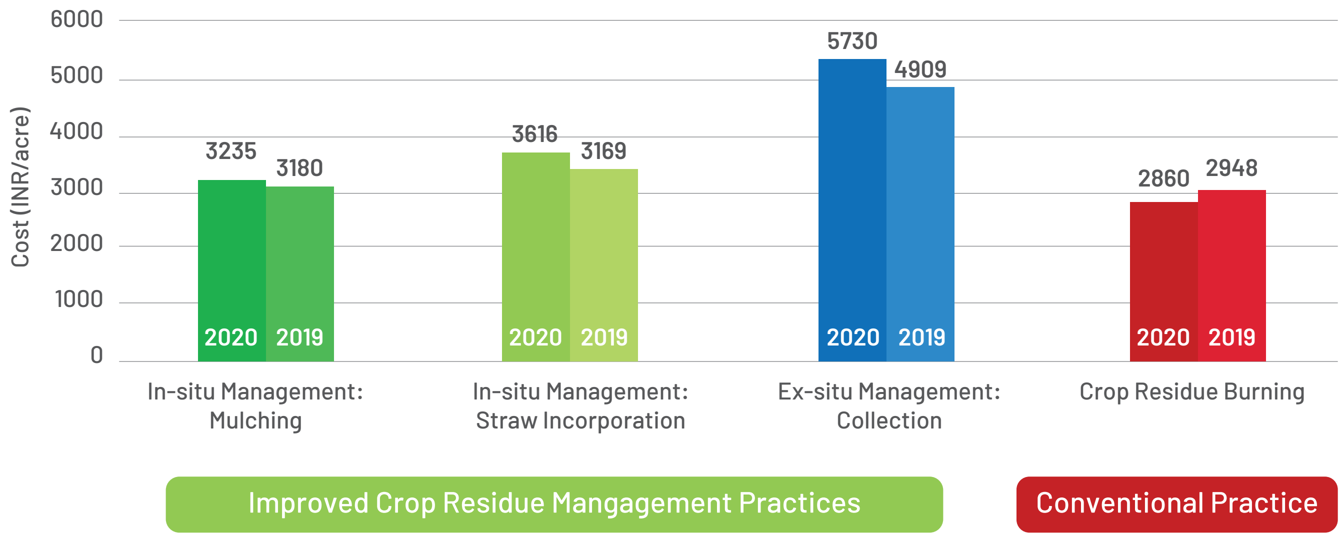
Source: CII Cleaner Air Better Life (2022) analysis

Note:

[1]Primary data collected from farmers which is representative of 172 intervened villages (average for all sampled farmers) in Punjab and Haryana in 2020
[2]Primary data collected from equipment manufacturers
[3]Based on group discussion with farmers and interviews with equipment manufacturers

Annexure 5

Change in cost of field preparation across adoption practice from 2019 to 2020



Source: CII Cleaner Air Better Life (2022) analysis

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