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'Cleaner Air - Better Life'
Initiative

Impact Assessment Report for Crop Residue Management Project

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Executive Summary

Air quality in Delhi National Capital Region (NCR) is a major concern due its severe impact on human health. During the peak pollution period in November 2018 more than 1800 primary schools had to be shut down in the region for the first time. It was time when CII partnered with NITI Aayog for the 'Cleaner Air Better Life' initiative in order to bring diverse stakeholders together for designing actionable steps and work on the identified solutions to address air pollution at the source.

Inspired by the leadership lent by the Ministry of Environment Forest and Climate Change to the 'Task Force on Biomass Management' (constituted by NITI Aayog under this initiative), CII rolled out the Crop Residue Management project in 2018 to curb the practice of crop residue burning in the North-Western States. Based on solutions identified by CII-NITI Biomass Management Report, the pilot project supported farmers undertake sustainable agricultural practices in the region. Demonstration efforts with farmers community were limited to two affected districts of Punjab in 2018. The **pilot interventions were rolled out by CII Foundation (CIIF) in September 2018, covering 16000 acres of farmland (targeted land) across 19 villages in Ludhiana and Patiala districts. With active engagement with 3000 farmers, there was a significant decline in stubble burning incidents in the selected villages and as a result of these efforts, 12000 acres farmland was made free from stubble burning**.

CII's Centre of Excellence for Sustainable Development (CESD) has carried out independent assessment of pilot project's impact. **Both particulate matter and carbon emissions were avoided as a result of adoption of more sustainable farming practices in the project area that have a direct and indirect impacts on environmental locally as well as globally**. In addition to these, there are numerous benefits for farmers by adopting the alternative and sustainable practices which were encouraged under this initiative. These benefits include **savings for farmers on cost and days of operations, nutrient recycling and carbon sequestration, water conservation, weedicide savings, improved yield, climate resilience of crops and lastly change in farmer's behaviour which is the major reason for burning**. A detailed bottom up approach is also used to understand various impacts and ground-level challenges for sustained adoption of new technologies and involves consultation with key stakeholder on the ground, focused group discussions with farmers communities, and primary data collection on different farming practices, and survey of rural households in intervened areas.

The **in-field management approaches including retention of straw as surface layer (mulching) and straw incorporation or mixing into the soil were promoted in the intervened area because of their potential to address this issue in environmentally sustainable and cost-effective manner** (See Figure 9). The key inherent challenge of this project was to provide various tools to farmers in a very short time duration to implement in-situ management of straw and collectively convince them to utilise these at the rural cluster level. To convince farmers to utilise alternate methods at large scale, CII Foundation successfully demonstrated the village-level participatory approach and farmers across different socio-economic strata were convinced to give up burning making this an inclusive model.

Analysis of the farmers survey shows that more than **74% of total farmland in three rural clusters across Ludhiana and Patiala was made free of crop residue burning in 2018 as opposed to only ~3% farmland which was free of crop residue burning prior to CII intervention in 2017**. The adoption rate in two clusters was found to be much higher, 87% and 71% in Raikot (Ludhiana) and Nabha (Patiala) clusters respectively, where needed in-situ management tools were provided to farmers. But lower adoption rate was recorded in the case of Samana (Patiala) cluster where farmers were provided financial support on per acre basis for adopting alternatives to burning. Rest of the project components including behaviour change communication, technical trainings/handholding, and participatory monitoring for burning incidents at the village-level remained the same across three clusters. Technical challenges were experienced in the intervened area of Nabha cluster where in-situ technologies were not technical feasible for rice-potato farmers due to infertile sub-soil conditions and therefore, collection and baling of biomass was also utilised at a significant level (~15% of farmland) in order to avoid burning. Promoted solutions for biomass management i.e. in-situ management is not only environmentally friendly but are also cost effective to farmers. Fuel consumption for field operations under the in-situ management methods like mulching and mixing was found to be either at par or lower than the conventional methods on case to case basis. **In-field utilisation is not only environmentally sustainable, it saves farmers substantial amount of time required for field operations after harvesting of rice: about 4-10 days, depending on the method**. Baling was found to have the highest environmental footprint[1] of all methods undertaken in this year and is also the most expensive method followed by conventional methods involving burning of straw and standing stubble.

Using a bottom up approach and conservative estimates, it is found that **more than 27 thousand tonnes of rice straw was avoided from being burnt in the year 2018 while nearly 25 thousand tonnes of rice straw was recycled (direct reuse at the field) back into the soil.** Crop residue burning acutely impacts the local air quality. It has a negative impact on rural population's health and associated with rise in public health expenditure. It is determined that more than one hundred tonnes of fine particulate matter emissions (115 tonne PM2.5) were avoided because of CII intervention which would have otherwise contributed to ambient air pollution locally and potentially across the Indo-Gangetic Plains. The **avoided pollutants comprised of 115 tonne PM2.5, 140 tonne VOCs, 82 tonne NH_3, 39 tonne NOx and 6 tonne SO_2 which had the potential to travel to wide distances and deteriorate the ambient air quality across Indo-Gangetic Plains**. Survey of rural households indicated more than 90% rural households in intervened villages agreed that air quality have significantly improved and termed it as either little or much better in the paddy harvesting season of 2018 compared to the last season (2017). Also, **29.85 kilo tonnes CO_2e of direct global warming impacts and 13 tonne Black Carbon were prevented as a result of averted burning of rice straw in 2018**.

The adopted practices also bring significant improvement to farmer livelihood and entire rural ecosystem. **Value of recycled nutrients (NPK and Sulphur) is estimated to be INR 410.87 per tonne of rice straw diverted towards in-field application. Overall value of recycled nutrients is therefore found to be INR 1 Crore for 25 thousand tonne rice straw recycled**

[1] It should be noted that the overall environmental footprint of baling will actually depend on its end-use application of biomass. Scope of this study is limited to the farmer fields and understanding overall environmental footprint of different ex-situ methods is an area of ongoing research.

in 2018. Recycled crop residue utlimately results into 29% savings on total fertiliser input cost for the rice-wheat cropping system. A key co-benefit of mulching is near elimination of weeds in the wheat crop and associated weedicide cost which is found to be as high as INR 2400-3200 per acre.

As a result of avoided requirement of pre-sowing irrigation which is associated with crop resdue burning practices and subsequently, a substantial reduction (-13%) in evaporative water losses during the crop growth, total water savings in this season are estimated to be 2.5 billion litres in the intervened area. This is an important co-benefit of adopted solutions given the repidly declining water table in the state. It should be noted that the complete farming data for the wheat crop, which was being harvested at the time of writing this reprt, is yet to be collected in intervened villages and savings on farm inputs are qunatified based on consultations with various local stakeholders and understanding from scientific literature. **Although there is no significant yield improvement expected for all the farmers in the first year but in consecutive years, crop yields are expected to undergo gradual improvement from 2% to 10% in the successfully intervened farmland.**

As discussed in the report, there is enough scientific evidence which proves that direct sowing of wheat at lower depth in soil, as carried out under the adopted methods, makes the resulting plants more resistent to extreme water and wind erosion. Promoted practices therefore enhance climate resilience of the crops, equipping farmers against the unexpected weather events induced by climactic change.

Farmers survey carried out across intervened areas in January 2019 pointed to soil-health, air pollution & health, and peer pressure as leading factors which proves the effectiveness of the behavior change communicaiton tools and participatory monitorning employeed by CIIF to check burning incidents in the villages.

As documented in the report, supply constraints were observed for procurement of in-situ management tools in 2018 on account of huge demand-supply gap for these tools. This issue needs to be addressed through timely procurement of tools. Also, the farmers need technical handholding beyond the 15-20 days of period for implementing alternative methods. Because of fundamental changes in farming practices, real-time support to address farmers’ concern is crucial for ensuring long-term sustainability of undertaken efforts. Management protocols and manuals for field staff at different levels are proposed to ensure sustained adoption of new technologies by farmers. These protocol and manuals should be able to address farmers’ apprehensions at different stages of agricultural operations though timely action, clear delineation of responsibilities and real-time support.

Despite its clear environmental merits, in-situ management cannot address the issue in entirety due to technical challenges as highlighted in the report. Ex-situ biomass management may therefore play an important role the overall ecosystem of biomass management as the options are proven for commercial deployment. The issue will require co-ordinated research in the future to understand cost-effectiveness and environmental sustainability of potential ex-situ solutions, considering a very high environmental footprint and cost of associated baling and collection operations as highlighted in the report.

Lastly, the penetration of soil-health card scheme is found to be very low in intervened area and enabling soil health cards for farmers is an important step which will enhance farmers’ capacity for science-based decision making and improve the long-term sustainability of adopted farming practices which are crucial for addressing air pollution and improving the soil health in Western Indo-Gangetic Plains where soil is severely degraded due to unsustainable farming practices and overexploitation of natural resources.

Summary of Impacts

Adoption of No-Burning Approach at Large Scale

- 74% of total farmland belonging to three rural clusters across Ludhiana & Patiala was made free of crop residue burning in 2018 as opposed to only 3% farmland free of crop residue burning prior to CII intervention in 2017
- 27 thousand tonnes of rice straw was avoided from being burnt in the year 2018 while nearly 25 thousand tonnes of rice straw was recycled back into the soil though direct reuse of rice straw at the field.

Avoided Air Quality (AQ) & Global Climate Impacts

- Avoided air pollutants: 115 t PM2.5; 140 t VOCs; 82 t NH_3; 39 t NO_x and 6 t SO_2
- 90% rural households in intervened villages agreed that ambient air quality better in the paddy harvesting season of 2018 compared to the last season (2017)
- Avoided direct global warming impact worth 30 kt CO_2e & 13 t Black Carbon (BC)

Cost-effectiveness & Environmental Sustainability of Promoted Solutions

- Fuel consumption for field operations under the in-situ management methods like mulching and mixing was found to be at par or lower than the conventional method depending on the actual choice of method
- Adopted methods saved farmers substantial amount of time required for field operations after harvesting of rice: 4-10 days, depending upon the choice of method

Nutrient Recycling & Carbon Sequestration

- Value of recycled nutrients is estimated to be INR 410.87 per tonne of rice straw diverted from burning to in-field application. This amounts to total 29% savings on fertiliser cost for the rice-wheat cropping system in consecutive years

Water Conservation

- Net water savings worth 2.5 billion litres in interveneed area which inlcude elimination of pre-sowing irrigation requirement and ~13% lower irrigation water requirement during wheat growth due to reduction in avaporative losses

Reduced Instances of Weed & Avoided Chemical Inputs

- Farmer saved INR 800-2400 per acre on weedicides which is otherwise sprayed 3-4 times in a season for weed named Phalaris Minor (Gullidanda) pervalent in the wheat crop

Improved Livelihood & Climate Resilience

- Gradual increase in crop yields 2-10% in consecutive years
- Adopted solutions promote climate resilience of the crop and reduce farmers risks in wake of climate change induced extreme weather events.

Farmer Behavior

- Farmers across different areas pointed to soil-health, air pollution & health, and peer pressure as leading factor; proving effectiveness of behaviour change communication and participatory monitoring under the porject

1. Introduction: Crop Residue Management Project

In November 2018, air pollution became a crisis in Delhi National Capital Region (NCR) and over 1800 primary schools were shut down in the region for the first time. In the same month, CII partnered with NITI Aayog for the 'Cleaner Air Better Life' initiative in order to bring diverse stakeholders together for designing actionable steps to address scientifically identified sources in Delhi NCR and make commitments to improve air quality across the region.

'Cleaner Air Better Life' Initiative held its first meeting on 05 June 2017, on the occasion of World Environment Day and subsequently, four task forces were constituted by NITI Aayog to identify strategies and actionable steps for addressing major sources identified by source apportionment study[2] of Delhi: transportation, fuel, industry and biomass management in the agrarian states surrounding Delhi.

The primary goal of the Task Force on Biomass Management was to identify actionable solutions to curb the practice of stubble burning in the north-western states of India. The Task Force was anchored by the Ministry of Environment Forest and Climate Change and actionable steps were identified by this taskforce by undertaking consultations with key stakeholders including the Punjab Agriculture University (PAU) and farmers community in Punjab in the year 2017. The final report of the task force including the action plan for Biomass Management was subsequently released in February 2018.

Specific recommendations included upscaling technologies for in-situ treatment (using service-based shared economy model and process-based incentives[3]), rewards and monitoring at local level, regulatory support to ex-situ business models, awareness and information tools for farmers etc (CII-NITI 2018). The report of the 'Sub Committee of High-Level Task Force on prevention of stubble burning in Punjab, Haryana and Western Uttar Pradesh' further took note of the CII-NITI report and suggested in-situ treatment as the most feasible and preferred method for addressing the problem. A central subsidy scheme was subsequently announced by Government of India for the affected states as part of the Union Budget 2018-19.

With the goal of galvanising Industry action for biomass management, CII Foundation (CIIF) initiated the crop-residue management initiative in two affected districts of Punjab to demonstrate the available options along with farmers' community in Punjab. Pilot projects were initiated in 2018 in three rural cluster belonging to districts of Ludhiana and Patiala, covering 19 villages. Details of these clusters and outcomes of this project are briefly summarised in Table 1.

The project was designed to develop a model for field interventions for upscaling biomass management technologies in rural communities of affected rural areas in North Western States. CIIF's intervention follows a holistic end-to-end approach consisting of (1) behaviour change communication, (2) financial support to farmers, (3) technical handholding, and (4) participatory monitoring of stubble burning at village level. Four key steps followed for implementation at the village level are briefly summarised in the supplementary material (SM. 1.) attached in this report.

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[2] available from IIT Kanpur (2016) at that time

[3] In order to address the problem of limited time window available to farmer between harvesting of rice and sowing of the next crop, mainly the wheat crop

Table 1. Key Outcomes of the Crop Residue Management Project

Rural Cluster	Villages	Delivery Model[1]	Channel Partners[2]	Targeted Farmland	Farmers	Area Intervened Successfully	
						Pre-intervention (2017)	Post intervention (2018)
[Block, District	[number]			[acre]	[number]	[acre]	[acre]
Raikot, Ludhiana	7	Machinery Support to Farmer Groups	3 FPOs	7,100	1,000	200	6,200
Nabha, Patiala	9	Machinery Support to Farmer Groups	3 FCSs	7,000	1,500	150	5,000
Samana, Patiala	3	Financial Incentives to Farmers	1 FCS	2,000	500	200	800
TOTAL	**19**			**16,100**	**3,000**	**550**	**12,000**

Source: Adaptation of CII Foundation reported Data as on March 2019

Note:

1. Broadly, two different delivery models were used to change farmers' behaviour in favour of sustainable agricultural practices- (a) Machinery support to farmers where required machinery was provided to the farmer groups to be used by entire village and (b) Farmers were financially incentivised on per acre basis (Rs 1000/ acre) for adoption of alternate practices.

2. Farmer groups in the intervened villages were used to engage farmers for adopting solutions for managing rice straw. These farmer groups include the Farmer Producer Organisations (FPOs) and Farmer Cooperative Societies (FCSs).

2. Background

Independent assessment is carried out by CII's Centre of Excellence for Sustainable Development (CESD) as per the best of the information collected independently by CESD team and explanations provided by the field teams at different levels. CII Foundation (CIIF), which is the implementation agency for this project, demonstrated sustainable farming practices in the rural clusters of Punjab by engaging with the rural communities in Ludhiana and Patiala districts of Punjab. The assessment involves collecting, analysing and interpreting information from the field in order to generate adequate evidence on impacts achieved under these demonstration projects in three village clusters of Punjab in 2018. Appropriate methods, as described in Section 3, were used to evaluate various impacts of this project. The report is structured into three five key sections. Besides the background and methodology, three key sections of this report are-

1. Impact assessment
2. key challenges and learnings
3. Possibilities for the future

The impacts, under Section 4, are further classified and presented under four key categories-

1. Technology adoption & avoided emissions
2. Impacts on local air quality and global climate
3. Cost effectiveness of promoted solutions
4. Improvement in farmer livelihood and rural ecosystem
5. Assessment of farmer's behaviour

Subsection 4.1 summarises the overall impact in terms of adoption of sustainable agricultural practices substituting burning of crop residue and emissions avoided as a result CIIF intervention in three rural clusters. These emissions are linked to environmental impacts at local as well as global scale. Subsection 4.2 throws more light on these environmental impacts and also presents an assessment of farmers' perception about improvement in ambient air quality.

Farmers accrue multiple benefits by adopting sustainable practices which were promoted under this project (Refer to in-situ treatment methods listed in the supplementary material SM.2). These benefits are estimated using a detailed bottom-up approach and presented under five key categories including- (a) savings for farmers on cost and days of operation. (b) nutrient recycling and carbon sequestration (c) water conservation (d) weedicide savings (e) improved yield and climate resilience. Farmer's behaviour, which is responsible for burning or adoption of new farming techniques is mapped under subsection 3.4.

Finally, the key challenges experienced in this year and learnings from project are presented in the Section 4. Based on these, Section 5 dwells on some of the key strategies for improving the initiative in coming years.

3. Methodology

Impact assessment relies on a combination of primary and secondary information for establishing and validating the impacts achieved under this project. Bottom up understanding of ground level issues was developed through consultation with various stakeholders in the intervened areas. These stakeholders included- the farmers in the intervened areas, farmer co-operative societies (FCSs), farmer producer organisations (FPOs), village Panchayats, operators of farm machinery, Krishi Vigyan Kendra (KVKs), field staff and volunteers of NGOs engaged by CII Foundation, co-operative inspectors and land surveyors in rural areas.

Focussed group discussions with farmers community and interviews with above stakeholders at different stages of programme implementation were crucial in developing the bottom up understanding of various impacts and challenged faced under the undertaken project (See Box 1). Another key source of primary data is the survey of rural households carried out in the intervened villages during December 2018-January 2019 (See SM 2. for survey questionnaire). While farmer survey was conducted in all intervened villages, focussed group discussions with farmers communities were held around the same time in ten of total nineteen villages in order to further validate key impacts the programme (See Box 1).

Sample size for the farmer survey was chosen based on random sampling of farmers or rural households involved in farming. For the known target population, the sample size was calculated by using standard formula for sample size calculation as given below. The required sample size was found to be 341 farmers or 341 rural households with agriculture as primary occupation.

$$Sample\ size\ (n) = \frac{pz^2}{4z^2(p-1)+z^2}$$

size of population surveyed (p) = 3000 farmers across three rural clusters in Punjab

margin of error (m) = 0.05, for 5% margin of error

z-score (z) = 1.96, typical z-score for margin of error at 5% & confidence level of 95%

Stratified random sampling strategy was used in order to have equal representation from each of the 19 intervened villages across three rural clusters in Ludhiana and Patiala. As per the latest information on intervened clusters (See Table 1), desirable number of samples in villages were further disaggregated as given in the Table 2 below. To ensure coverage of the entire village population (rural households) evenly and as randomly as possible, the field team consisting two members (one supervisor and one enumerator each) per team went in four different directions in the surveyed villages.

Table 2. Random Sampling in Intervened Villages

S. N.	Rural Clusters	Intervened Villages in Three Clusters	Samples per cluster	Samples per village
	[Block, District]	[villages]	[rural HHs][1]	[rural HHs]
1.	Nabha, Patiala	Jasso Majra; Halla; Fatehpur; Govindpura; Malewal; Malewal Patti; Kalsana; Bhore; Lopa	171	19
2.	Raikot, Ludhiana	Boparai Khurd; Ramgarh Sibian; Rajgarh; Dhurkot; Shahjahanpur; Govindgarh; Kalsan	114	17
3.	Samana, Patiala	Dodra; Kotli; Bhedpuri	57	19

Source: CII-CESD (2019)

Box 1. Focussed group discussions with farmers held in December 2018 by research team in the intervened villages of Halla (Upper Left), Gobindpura (Upper Right), Kalsana (Lower Left); and farmer survey being carried out by field staff and volunteers in rural household of Raikot Cluster of Ludhiana, Punjab (Lower Right)

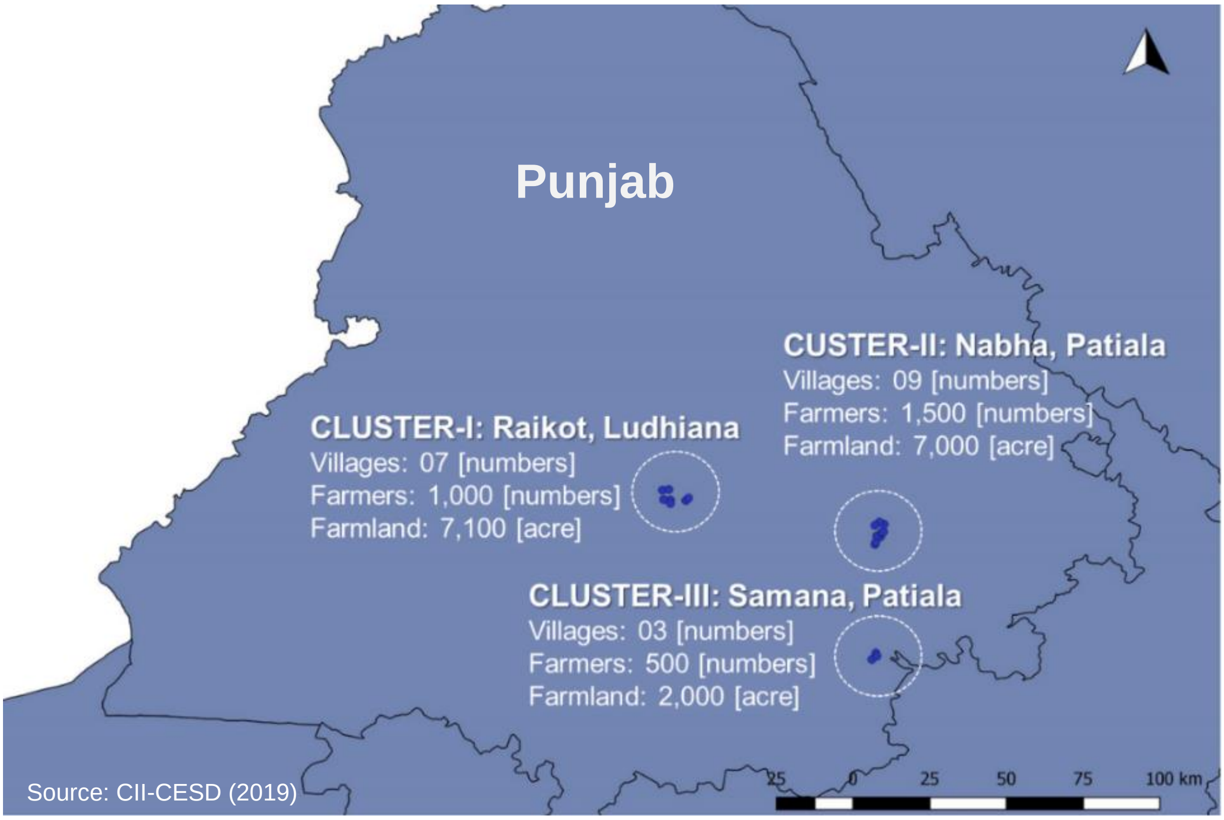



4. Impact Assessment

4.1 Technology Adoption & Avoided Emissions

Villages intervened by CII Foundation are mapped in the Figure 1 using the coordinates from central locations in intervened villages. It also highlights the key statistics of these three rural clusters named after their respective blocks: Raikot in Ludhiana and Nabha and Samana in Patiala.

Figure 1. Location of Intervened Villages across



In-field/in-situ management rice straw was promoted in intervened villages based on its advantages and potential to address the biomass burning at the source in environmentally friendly and cost-effective manner (Refer to Figure 9). Depending on the next crop sown, these techniques require deploying various farm implements such as Super SMS, mulcher, cutter-cum-spreader, happy seeder and mould board plough (See Supplementary Material SM. 3) in order to treat and manage the straw in the field.

Required tools were procured by CII Foundation based on needs highlighted by farmers at village-level meetings. Using a village-level participatory approach, farmers were convinced to adopt these practices at large scale. Letting farmers choose the methods and required configurations resulted in gaining more adoption from farmers (See Table 1) due to minimized technology risks. As reported in the CIIF (2019) Report, there were instances where farmers divided their operation landholdings for experimenting with different methods including conventional and new methods. Figure 2 shows two adjacent fields in Raikot cluster which are sown using two new adopted methods- mulching and mixing of rice straw back into the field. Broad classification of methods, including conventional and newly adopted methods and configuration of tools required for these, is presented separately under the SM. 3.

Figure 2. Adjacent Wheat Fields in Project Area Sown using two Different Alternates

Conventional method of sowing wheat is preceded with complete burning of the standing stubble and residual straw from paddy crop in the field. Residual straw is either spread manually by farmer or less commonly it is cut by cutter spreader to burn it after drying. Under conventional approach, repeated ploughings are undertaken, once the straw has been burnt and fields is watered in order to maintain optimal soil moisture for sowing the next crop. This results into extra cost and time for farmers (See Figure 9.). Farmers, at times, partially burn the excessive amount of straw left on the field after the combine harvester operation. Here, the differentiating factor from the conventional method is that farmer do not evenly spread the residue after combine harvester operation or cut the whole straw but rather set the pockets with residual straw on fire. Burning in this case lasts only few hours and farmers can then manage the residual straw using alternate methods. This is especially prevalent with rice varieties such as Pusa-44 with longer paddy plants, generating higher amount of crop-residue. Large amount of straw on the surface is problematic for efficient tilling operation (with happy seeder or rotavator), especially, in the sandy or highly moist soil conditions. This technology hybridisation, observed here, will inevitably be a part of long-term transition until farmers adopt improved varieties of paddy or existing technologies are improved to handle excessive amount of straw. The hybridisation of farming techniques observed here is induced through a combination of factors consisting of-

1. Despite the new or improved varieties (early maturing varieties with lower water and crop-residue footprint) which are available with the same or higher yields, many farmers still continue to rely on old varieties of rice such as pusa-44 which are not environmentally efficient and not recommended by State Agriculture Universities[4].
2. Limitation of new technologies/tools such as super SMS or happy seeder for a smooth operation in a field with excessive straw, field which is not levelled properly or not strewn evenly with crop residue.
3. A large section of farmers, especially the medium-large farmers, adopted different tool configurations in order to divide the technology risks. Some of these farmers even divided the operational farmland under the new practices as well as conventional method.

Mulching is a conservational[5] and climate smart agricultural practice where rice straw is retained onto the surface as a cover/mulch by chopping/shredding it to smaller pieces and spreading it evenly on the ground. This operation can be undertaken while rice is being harvested or once the field is harvested. The earlier technique requires Super SMS to be attached to the combine harvester while later requires additional run of mulcher or cutter cum spreader (mounted onto a tractor) once the field is harvested. The field covered with mulch is subsequently sown with the conservational or so called zero-tillage method using happy seeder which sows wheat in a field covered with mulch.

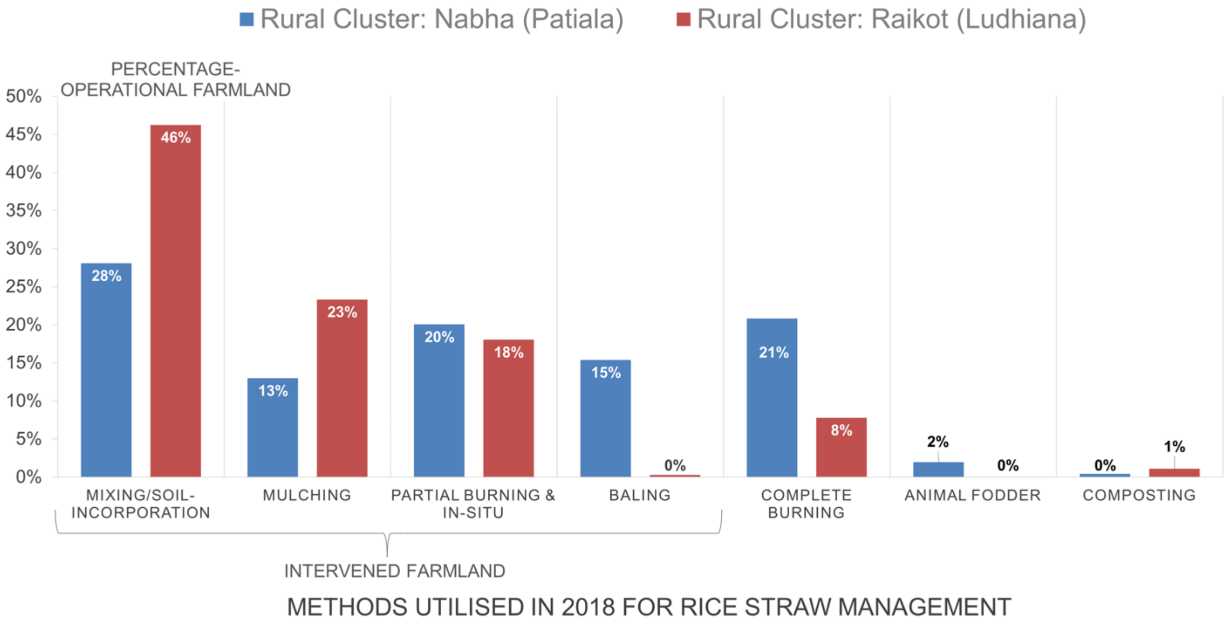
Soil incorporation or mixing is similar to mulching as far as the first stage is concerned which is chopping/cutting the rice straw and evenly spreading it in the field. The key line of differentiation here is that straw is not retained as the top layer. It is rather mixed or incorporated into the soil during the sowing operation. It is a preferred method for in-situ treatment by potato farmers or farmers who already own rotavator. Later is usually the case with rich farmers in Punjab who own rotavator. Either rotavator or Mould Board (MB) plough is utilised for mixing the rice straw depending on the choice of next crop to be sown by the farmer. Rotavator with seed drill is adequate for mixing rice straw into the soil before sowing the wheat crop but MB plough is preferred choice by the potato farmers as potato's growth is hampered by excessive straw in the top layer and the moisture it attracts. MB plough mixes the straw much deeper into the soil compared to rotavator and solving this challenge.

Under baling/collection, baler is used to make compact bales of paddy stubble. Two machines are required to enable this- raker for heaping straw into rows and baler for compacting the straw into bales. Raker make single linear heaps of straw and baler compacts it into rectangular or cylindrical bales depending of type of baler used. Once straw is baled at the field, custom built trolleys are used for transporting these bales directly to end users or conversion plants for further processing rice straw into useful products or fuels (ex-situ management). Although baling and transporting rice straw is energy intensive it is still a preferable method for potato farmers with sandy or sand-loamy soils. As explained under the soil incorporation method, MB plough is the only practical choice for in-situ management of rice straw for the potato farmers. But MB plough operation also turns out to be problematic for

[4] Punjab Agriculture University (PAU), Ludhiana in case of Punjab
[5] Not requiring intensive tilling operation which is common with conventional agricultural practices

potato farmers, especially in case of sandy or sand loamy soil conditions. As it ploughs much deeper into the soil, it disturbs the more fertile top soil and impacts the productivity of potato crop. Whereas, under baling/collection, once the baler has cleared the field, farmers can use conventional method to till the soil and sow the next crop.

Figure 3. Management Options Used by Farmers in Project Area



Source: CII-CESD (2019) Analysis of Farmer Survey Data

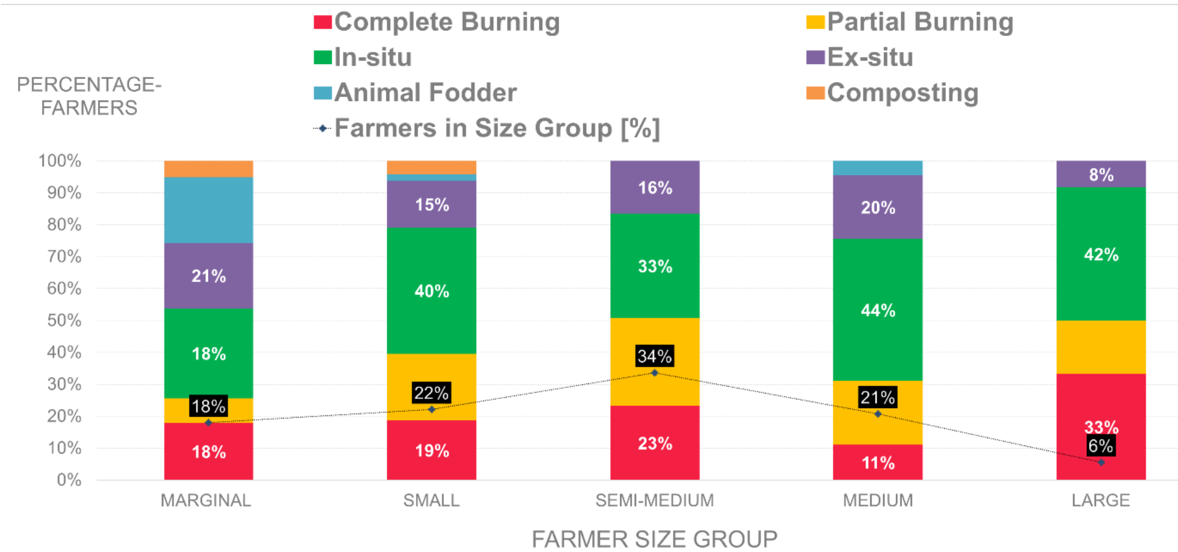
Based on the analysis of farmer survey, key impacts achieved in terms of adoption of alternate and more sustainable agricultural practices, in the two clusters of Ludhiana and Patiala (Nabha and Raikot respectively) in 2018 are highlighted in Figure 3. It can be seen in the Figure 3 that complete burning incidents were only limited to 21% and 8% farmland across intervened area in Nabha and Raikot respectively in 2018. 69% and 58% of the total farmland in Raikot and Nabha blocks respectively was made totally free of stubble burning (free of complete/partial burning). In total, **87%** and **78%** of total farmland in Raikot and Nabha clusters, respectively, was made free of complete burning. Apart from promoted methods of mulching of mixing of straw (so called in-situ treatment) (See SM 3 for an overview of different methods), this includes the land under partial burning and in-situ due to inefficiency of existing technologies in fields with excessive straw and ex-situ treatment due to lack of viable technical options for in-situ treatment in rice-potato farms**.** As per the cooperative records, there are significant number of rice-potato farmers in Nabha (~238 acres) compared to Raikot (~90 acres). Also, the soil conditions are sandy or sand loamy with infertile subsoil layers which led to significant adoption of baling as an alternate to in-field treatment in Nabha area.

In both cases, adoption has been in the favour of in-situ practices which were promoted as alternate to stubble burning to the farmers. But due to soil conditions being a limiting factor in the intervened area in Patiala; ex-situ treatment i.e. baling, and evacuation of biomass was also practiced to significant level (i.e. 15% of farmland in Nabha Cluster). The farmland under partial burning (due to excessive rice straw in certain pockets) and ex-situ treatment are implicitly considered as successful cases by the implementation teams, as reported in the Table 1). The total farmland made free of complete stubble burning in these two clusters is reported by CIIF to be **89%** and **71%** in Raikot and Nabha clusters respectively. An error margin of 5% is expected in the survey results as described in the methodology section and very insignificant differences are observed in the survey data from the field and actual impacts reported by implementation team. The observed deviations are found to be +1% and +6% in sampled data for achieved impact in Raikot and Nabha clusters respectively. Hence it is established that impacts observed using farmer survey corroborate with the project outcomes reported by implementation team within a reasonable level of accuracy.

Although rice straw from hybrid varieties is not directly usable as animal feed[6], a small portion of rice straw is being utilised (See Figure 3) by mixing it with other crop residues such as wheat straw. Animals' dislike for rice straw as feed and declining share of decentralised dairy farming culture in Punjab are both understood to be primary reason for low adoption of rice straw for animal feed. Also, composting of rice straw is practiced in intervened areas to a very small extent (Figure 3). It is an attractive proposition with farmers who have availability of labour and land. The common form of composting associated with rice straw is pit composting where rice straw is mixed with cow dung and water, and subsequently left buried in the pit for 4-6 months.

In Punjab, the farmer landholdings, which are categorised as marginal (<1 ha) and small (1-2 ha) are observed to be more 35% (< 2 ha) of total farmers as per the Information from Agricultural Census (2011) (Refer Figure SM4.1 under Supplementary Material SM 4.). As per the same source, the figure is slightly below the state average in both Ludhiana and Patiala at ~30% whereas the large farmer landholdings (>10 ha) vary from 7-10% in Patiala and Ludhiana. The semi-medium to medium scale farmers in both the districts constitute about ~60% of all farmers. The survey findings also indicate that number of marginal farmers (<1 ha) are significantly higher in intervened rural areas in Patiala (18% of all farmers) compared to Ludhiana (6% of all farmers) which corroborates with the information from local stakeholders. This information matches with the surveyed farmers who are represented under different size categories in Patiala and Ludhiana in Figure 4 and Figure 5 respectively. These figures indicate the adoption rate of new technologies across different size classes.

Figure 4. Utilisation of Management Options across Size Groups in Nabha cluster

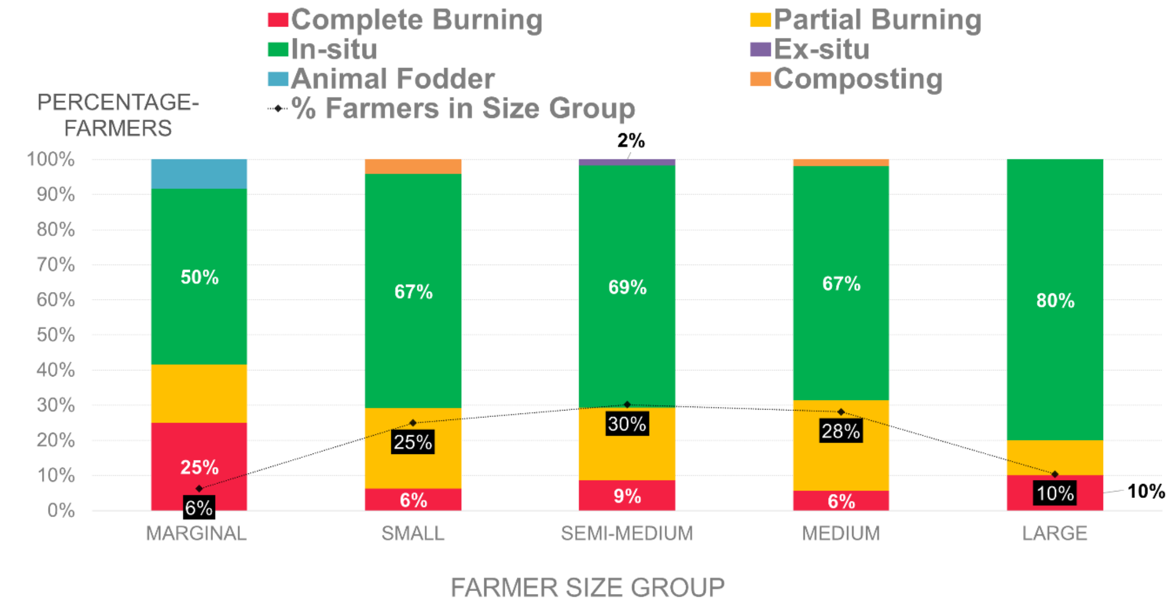


(Patiala)

Source: CII-CESD (2019) Analysis of Farmer Survey Data

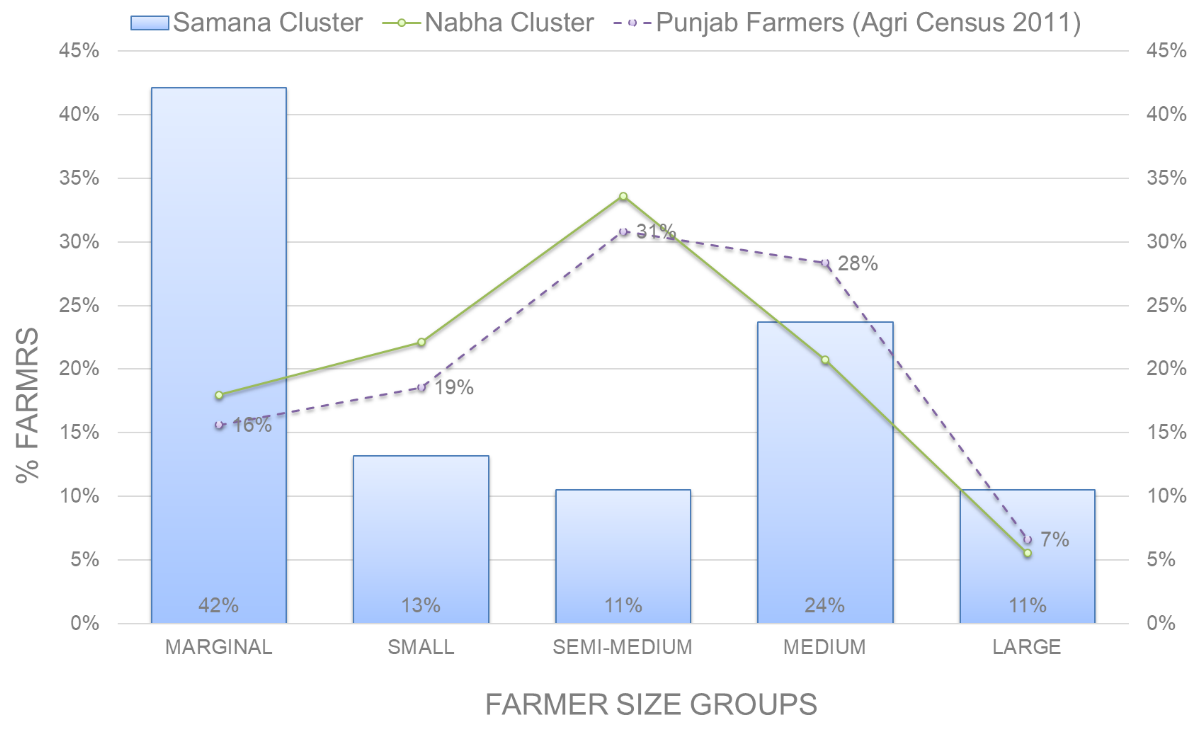
[6] as animal do not like the rice straw, high in silica (based on inputs from farmers in intervened villages)

Figure 5. Utilisation of Management Options across Size Groups in Raikot cluster (Ludhiana)



Source: CII-CESD (2019) Analysis of Farmer Survey Data

Figure 6. Farmers across Size Classes in Samana Cluster who Adopted Alternate Practices Substituting Crop Residue Burning



Source: CII-CESD (2019) Analysis of Farmer Survey Data

In case of Samana cluster, where farmers were financially supported for undertaking sustainable practices on 800 acres of farmland, the actual data of these farmers (farmers and associated farmland) is used for evaluation. Results for this cluster are presented separately in the Figure 6, depicting the aggregated information on total farmland, under differently sized farmers, which was made completely free of stubble burning. Actual data form the field shows that 40% of the target area or 800 acres of farmland in Samana was made free of stubble burning. While comparing results with Figure 4 and 5, it can clearly be seen that adoption of new methods was significantly skewed in favour of marginal farmers. The adoption with large farmers is comparable in all three rural cluster but it is found to be relatively low in the case of Samana cluster for small to semi-medium farmers. Hence a conclusion can be drawn that creating hard infrastructure at community level along with end to end support is a more inclusive approach and results into higher adoption across all farmers.

Table 3. Avoided Burning and Rice Straw Recycled back into the Soil

S.N.	Rural Cluster	Farmland under alternate use of rice straw in 2018	Straw utilisation	Rice straw avoided being burnt	Rice Straw recycled back into the soil
	[Block, District]	[acre]	[% method]	[tonne]	[tonne]
1.	Raikot, Ludhiana	6200	79% In-situ 21% Partial in-situ 00% Baling	14177	14177
2.	Nabha, Patiala	5000	54% In-situ 26% Partial in-situ 20% Baling	11190	8677
3.	Samana, Patiala	800	67% In-situ 33% Partial in-situ 00% Baling	1738	1738
	Total	**12000**		**27104**	**24591**

Source: CII-CESD (2019) analysis based on Kumar et al (2015), CIIF (2019) reported data, and farmer survey data

Avoided Atmospheric Emissions

It is 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). Using a conservative estimate of 2.5 tonne rice straw generated per acre, total amount of rice straw which was avoided being burnt in 2018 is calculated as given in the Table 3. It is estimated that **more than 27 thousand tonne of rice straw was avoided from being burnt in 2018 as a result of CII intervention in Punjab while nearly 25 thousand tonne of rice straw was recycled back into the soil.**

Based on emission factors for rice straw burning from various sources as compiled and listed in Shrestha et al (2012), average emission factors were calculated and applied for understanding the avoided emissions as a result of this project. These emission factors are listed in the Table 4. Avoided emissions as a result of this project are calculated in the same table assuming 'dry matter to crop residue ratio' of 0.85 and 'burning efficiency ratio' of 0.87. As listed in Table 4, these emissions include both particulate matter (PM) emissions and gaseous emission. Total particulate matter (PM) emissions include coarse (PM 10) and fine particulate matter (PM 2.5) emissions. The Black Carbon (BC) emissions fall within the fine particulate range (PM 2.5). There is significant amount of Organic Carbon (OC) emissions which is simply the unburnt carbon that gets released into the atmosphere during inefficient combustion or open burning of biomass. Gaseous emissions include Carbon dioxide (CO_2), Carbon monoxide (CO), Methane (CH_4), Volatile Organic Compounds (VOCs), Ammonia (NH_3), Oxides of Nitrogen (NOx) and Sulphur dioxide (SO_2). These atmospheric emissions are further described and disaggregated into air and climate pollutants in subsequent section (Subsection 4.2).

Table 4. Avoided Atmospheric Emissions in the Project Area

S.N.	Pollutants		Emission Factors for rice straw	Avoided atmospheric emissions
			[g/kg dry mass of residue]	[tonne]
1	Particulate emissions	PM	9.64	193
2		PM10	6.30	126
3		PM2.5	5.75	115
4		BC	0.64	13
5		OC	2.20	44
6	Gaseous emissions	CO_2	1220.32	24459
7		CO	101.29	2030
8		CH_4	9.60	192
9		VOC	7.00	140
10		NH_3	4.10	82
11		NO_X	1.95	39
12		SO_2	0.29	6

Source: CII-CESD analysis based on Shrestha et al (2012), Kumar et al (2015), CIIF (2019) & farmer survey data

4.2 Impacts on Air Quality and Global Climate

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). As per inputs from villagers, rice-straw burning in October and November exacerbates smog and gives rise to poor visibility on the road which is a potential safety hazard.

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. Black carbon (BC) emissions, which again form a part of PM 2.5 emissions, are Short-Lived Climate Pollutants (SCLPs) and cause radiative forcing. Coarse particles with a diameter of less than 10 microns (PM10), including fine particles less than 2.5 microns (PM2.5) pose the greatest risks to health, as they are capable of penetrating peoples' lungs and entering their bloodstream.

It is estimated that **more than hundred tonnes of fine particulate matter (~115 tonne PM2.5) emissions were avoided as a result of CII intervention which would have otherwise contributed to ambient air pollution locally and potentially across the Indo-Gangetic Plains**.

The **largest amount of pollutant avoided from burning rice straw was Carbon monoxide amounting to nearly two thousand tonne CO**. Second largest gas avoided was VOCs. Roughly, **140 tonne VOCs were avoided as a result of farm interventions**. Familiar 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 figure 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. Out of the seven air pollutants listed in the Table 5, which were avoided in this project, six are part of India's NAASQ with only exception of VOCs. Key health and environmental implications of these pollutants are also highlighted in the Table 5.

Apart from direct air pollution and health impacts, many of these pollutants, as highlighted in Table 5, also contribute to ground-level Ozone and fine-ultrafine particulate matter. Ground-level ozone is produced when carbon monoxide (CO), methane, or other volatile organic compounds (VOCs) are oxidized in the presence of nitrogen oxides (NOx) and sunlight (WHO 2019). As given on Table 4 and 5, all required ingredients for Ozone are generated at the site of biomass burning. 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.

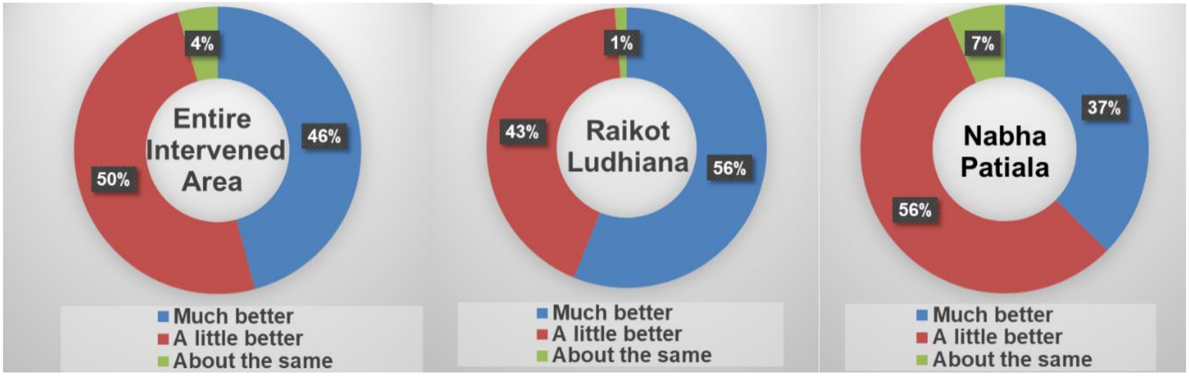
As listed in Table 5, the **avoided pollutants amounting to 115 tonne PM2.5, 140 tonne VOCs, 82 tonne NH_3, 39 tonne NOx and 6 tonne SO_2 had the potential to travel to long distances and degrade the ambient air quality across Indo-Gangetic Plains.**

Table 5. Air Pollutants Avoided at Source and their associated Health cum Environmental Implications					
Category	S.N.	Pollutant	Avoided emissions [tonne]	Heath Implications	Environmental Implications
Coarse particulate matter	1.	PM 10	126	• Acute lower respiratory infections • Cardiovascular disease • Chronic obstructive pulmonary disease • Lung cancer	• Fine PM travels and causes air pollution at local, regional and global scales within few days to weeks • BC, a component of PM2.5, is one of the largest contributors to global warming after CO_2 • Causes smog, affecting visibility
Fine particulate matter	2.	PM 2.5	115		
Gaseous Emissions	3.	Carbon monoxide (CO)	2030	• Dangerous in closed environment • Long-term exposure to low concentrations is also associated with a wide range of health effects. • Increase in CO levels linked to congestive heart failures and hospitalizations	• Precursor to ground level Ozone
	4.	Volatile Organic Compounds (VOCs)	140	• Eyes, nose and throat irritation • Difficulty breathing and nausea • Damage to central nervous system as well as other organs • Some VOCs are carcinogenic	• Precursor to ground level Ozone • Precursor to fine/ultrafine secondary particles
	5.	Ammonia (NH_3)	82	• Cough, phlegm • Wheezing • Asthma	• Precursor to ground level Ozone • Precursor to fine/ultrafine secondary particles
	6.	Oxides of Nitrogen (NO_X)	39	• Bronchitis • Asthma • Reduced lung function growth • Exposure linked to premature mortality and morbidity from cardiovascular and respiratory diseases	• Precursor to fine/ultrafine secondary particles
	7.	Sulphur dioxide (SO_2)	6	• Inflammation of the respiratory tract • Affects lung functions • Hospital admissions for cardiac disease and mortality increase on days with higher SO_2 levels	• Precursor to fine/ultrafine secondary particles

CII-CESD (2019) Analysis based on Shrestha et al (2012), Myhre et al (2013), CPCB (2014), Kumar et al (2015), CIIF (2019) & farmer survey data, ALA (2019), and WHO (2019)

Further, as part of the farmer survey, rural households were explicitly asked about local air quality improvement in their respective villages. As shown in the Figure 7, it is found that **more than 90% rural households in intervened villages agreed that air quality was either little better or much better in the paddy harvesting season of 2018 compared to the previous year (2017)**. The responses from rural households were recorded on a Likert scale of five. It is worth noting that although few households (4%) chose no significant change from the last year, none of the sampled rural households (including those who burnt crop residue in this season) chose worse air quality (little/much worse). Also, as noted in the CII Foundation project status report, there is anecdotal evidence of air quality improvement in the intervened villages (CIIF 2019) and reduction in health expenditure as a result. But no conclusive evidence could be drawn from farmer survey on reduction in health expenditure in October and December due to limited number of responses for this.

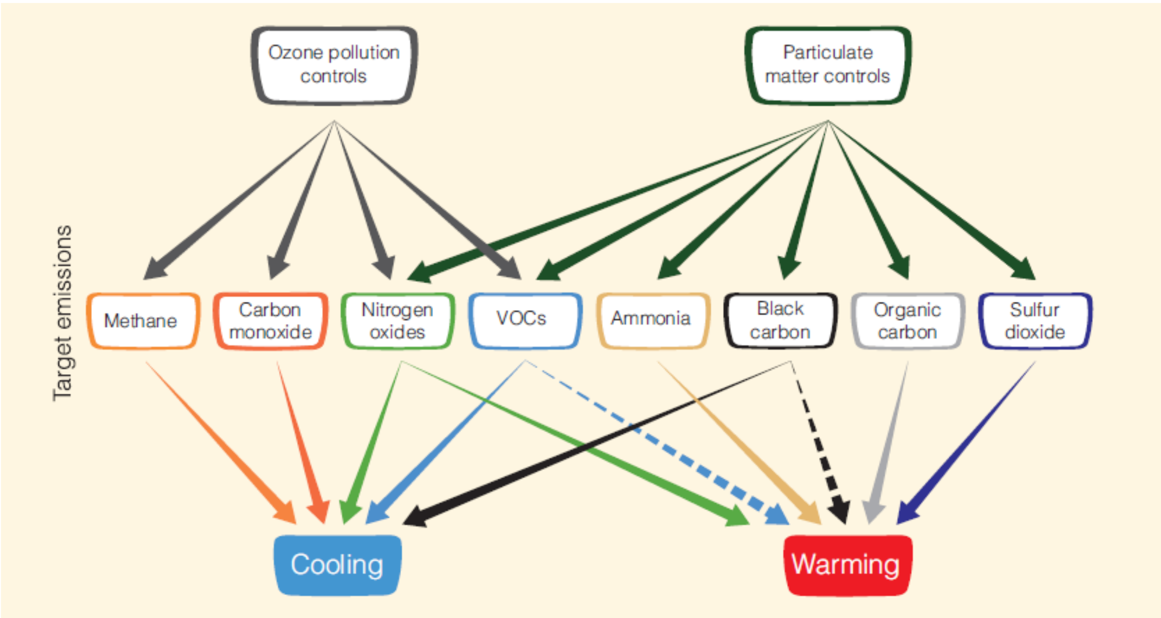
Figure 7. Response from rural households on air quality improvement in the harvesting period-2018 compared to last year in 2017.



Source: CII-CESD (2019) Analysis of Farmer Survey Data

Also, when asked about other major sources of air pollution, rural households mentioned transportation, industry, waste burning, agricultural mandis as other prominent sources of air pollution (listed in the order of precedence based on the responses received from sampled households). The reason why more farmers in Raikot (Ludhiana) perceive much better air quality compared to Nabha, Patiala is possibly due to specific location of these rural clusters and predominant wind directions from nearby commercial hubs during the paddy harvesting season. Our analysis of the weather data (WOI 2019) in this season reveals that the rural cluster of Raikot is located 62.5 km South West from nearby major commercial hub which is Ludhiana city and wind direction was found to be extremely low (near-zero) in this direction. The rural cluster of Nabha is located 35 km in the North West direction from Patiala city and received 22% of the wind from city in this period.

Figure 8. Impact of pollution controls on specific emissions and climate impact. Solid black line indicates known impact; dashed line indicates uncertain impact.



Source: Myhre et al (2013)

As presented in Figure 8, controlling many of the pollutants will also result in cooling the climate. These include BC, VOCs, CO and CH_4. As NOx can lead to both warming and cooling, only climate pollutants with net global warming impacts were considered here for estimating climate impacts of farm interventions. Using 100-years Global Warming Potentials (GWPs)[7] for emitted greenhouse gases which contribute directly to global warming, it is estimated that **approximately 29.85 kilo tonnes CO_2e of direct global warming impacts were averted due to CII's intervention in Punjab**. These calculations are presented in the Table 6.

Besides this, estimated **13 tonnes of BC were avoided as part of PM2.5.** BC is short-lived climate pollutant and despite its short atmospheric lifetime, it 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).

Table 6. Major Global Warming Impacts avoided due to Interventions in Punjab

S.N.	Greenhouse gas	Avoided emissions	Global Warming Potential (GWP $^{100\ years}$)	Avoided Global Warming Impact
		[tonne]	[g CO_2e/ g GHG]	[k tonne CO_2e]
1.	CO_2	24459	1	24.46
2.	CH_4	192	28	5.39
Total				**29.85**

CII-CESD (2019) analysis based on Shrestha et al (2012), and IPCC Fifth Assessment Report (Myhre et al 2013), Kumar et al (2015), CIIF (2019) & farmer survey data

4.3 Cost-effectiveness & Environmental Merits of Promoted Solutions

New methods adopted in villages saved farmers the high operational expenditure associated with the conventional practices predominant in previous year. Conventional method requires multiple ploughing operations with different tools and incur substantial amount of operational expenditure including fuel and labour charges. Multiple operations also take longer time between harvesting rice and sowing wheat. In-situ treatment is not only cost-effective, it saves farmers crucial time between harvesting rice and sowing wheat (See Figure 8). It has been documented in literature that conservation tillage practices offer 15-20% savings (INR 810-1215 per acre) on production of wheat by reducing four to eight tillage operations practised under conventional tillage (Ram et al 2018).

Figure 8 highlights cost, fuel and time required under different methods used by farmers for biomass management. A detailed bottom up approach was used to develop these estimates. Actual data from intervened villages in Patiala and Ludhiana was collected from local stakeholders on the ground including the field staff, volunteers, operators of farm machinery, farmer cooperative societies and private service providers. Although the cost of operations varies from farmer to farmer, depending on ownership of tools, this analysis takes into account different cost components like hardware, maintenance, fuel, labour by using a bottom up methodology as illustrated in the Table SM 5.1 and SM 5.2. Various assumption used for analysis were validated with farmer group discussions and are listed in the Supplementary

[7] Fifth Assessment Report (5AR)

Material SM 5. In order to arrive at cost comparison of different methods followed by farmers including conventional and new methods, it is assumed that farmers rent all required machinery from custom hiring centre maintained by farmer groups (FCSs/FPOs) while combine harvesting and baling services are offered by private service providers. Average rents for these services, as charged by cooperative societies and service providers around intervened areas in Patiala and Ludhiana, were used for this cost analysis (See Table SM 5.1). For comparing the days of mechanised operation across different methods, average farmer landholding comprising about 10 acres (Punjab) was taken into consideration.

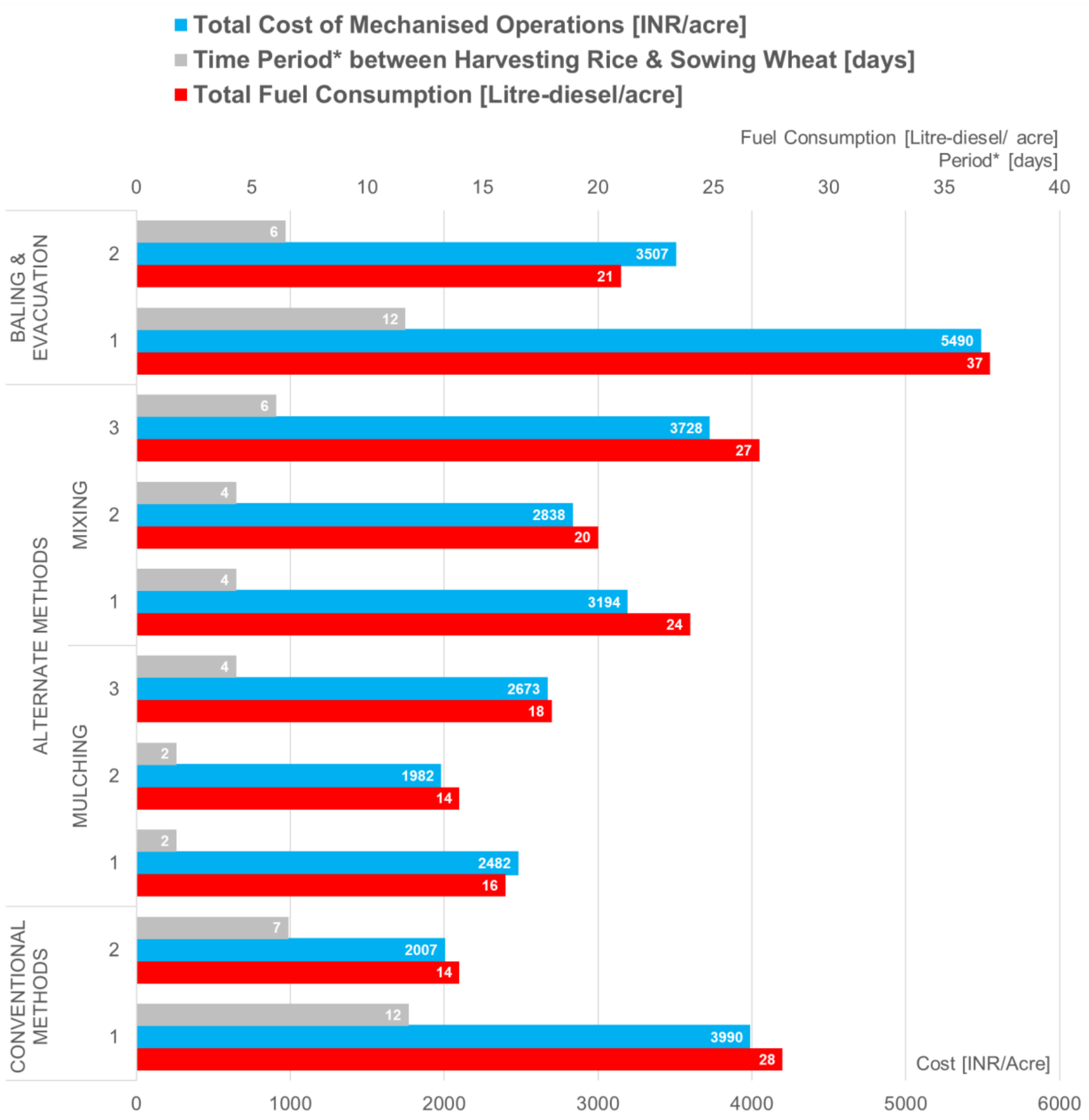
Fuel consumption of promoted methods (mulching/mixing) is found to be at par or lower than the conventional method depending on the actual choice of method.

The promoted solutions for biomass management are not only environmentally friendly, they are also cost effective (See Figure 9).

In-field utilization saves farmers substantial amount of time on field operations for preparation of land and sowing after harvesting of rice, about 4-10 days, depending on the choice of method.

The baling is the most expansive method and found to have the highest environmental footprint of all methods undertaken in this year, but actual footprint and cost will depend on actual end-use application of straw which is an area of ongoing research.

Figure 9. Cost, Fuel and Time Required under Different Methods Used by Farmers for Biomass Management



* For an average-sized farmer in Punjab with operational landholding ~10 acre

Practice	Cost of mechanised operation [INR/acre]	Fuel consumption [Litre-diesel/acre]	Time period for operations between harvesting rice and sowing wheat [days]
Conventional with burnings	2007-3990	14-28	7-12
In-field Mulching	1982-2673	14-18	2-4
In-field Mixing	2838-3728	20-27	4-6
Baling	3507-5490	21-37	6-12

Source: CII-CESD (2019) Analysis based on field data

4.4 Improvements in Farmer Livelihood and Rural Ecosystem

In-situ management or in-field mulching/mixing of rice straw leads to positive changes in farmers livelihood. It leads to multiple benefits to farmers some of which are listed and quantified in this section. Quantifying all above impacts is a challenging task but an attempt is made in this report to estimate these impacts based on best of the information available to us. Findings from the field are further reinforced with the secondary research inputs used to validate and estimate these benefits in monetary terms wherever possible.

4.4.1 Nutrient Recycling and Carbon Sequestration

Nutrient recycling by diverting the straw back to soil which reduced dependence on chemical fertilisers in long-term. Burning of one tonne paddy straw reportedly releases 5 kg Nitrogen (N), 2.3 kg Phosphorus (P), 25 kg Potassium (K), 1.2 kg Sulphur (S) into the atmosphere (Kumar et al 2019) and avoided burning of rice straw will add the commensurate value of nutrients to the soil. Using a conservative estimate, rice straw generation rate as assumed in Section 4.1 and fertiliser rates[8] as per the Nutrient Based Subsidy (NBS) (GoI 2019), the **value of recycled nutrients is estimated to be INR 410.87/tonne of rice straw diverted from burning to in-field application**. Total fertiliser cost of wheat and rice cropping system in Punjab is approx. INR 3485/acre (INR 2180/acre and INR 1305/acre for wheat cost and rice respectively) as per the latest information on 'Cost of Cultivation' available from public sources (DES 2019) for the year 2015-16. Recycling crop residue brings significant savings which amounts to **~29% of total fertiliser input cost for the rice-wheat cropping system[9]**. **Overall value of recycled nutrients in 2018 (24,591 tonne rice straw, See Table 3.) translates to INR 1 Crore.**

It should be noted this is aggregate fertiliser savings from this season's effort and may manifest itself over extended period in different crops sown by farmer. As per secondary sources, 15-20% direct fertiliser savings are reported in the next crop after mulching/mixing the rice straw in consecutive 2-3 years (Kumar et al 2015).

Whereas P, K and S are lost partially by 25%, 20% and 60% respectively due to burning of rice straw, nearly 90% of N and nearly 100% of Carbon (C) gets lost in the process (Kumar et al 2019). Loss of C is estimated to be 0.97 tonne C/ acre (Kumar et al 2019). Soils in the Indo-Gangetic Plains are severely degraded with soil organic carbon (SOC) content estimated at or below 0.1 per cent[10] which has implications for environmental quality, and food security as a result (Paroda et al 2018). An increase in 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 residue addition with minimum to zero-till is linked to 17-25% higher SOC compared to conventional tillage practices (Lohan et al 2017). Paroda et al (2018) estimates that ecosystem services for sequestering 0.33 tonne SOC per hectare per year can be priced at INR 2,500 per hectare per year.

[8] NBS rates for 2018-19 (INR per kg) are 18.901, 15.216, 11.124, 2.722 for N, P, K, and S respectively (MoCF, 2018)

[9] Cf. Lohan et al (2017) estimates 15-20% savings considering addition of Nitrogen and Phosphorus from rice straw

[10] This is far below the critical threshold of 1.5 to 2.0 per cent needed for healthy soils

4.4.2 Water Conservation

Pre-sowing irrigation water requirement is eliminated due to avoided burning. Also, maintenance of soil moisture by the mulch layer further leads to enhanced water-use efficiency in subsequent crops due to enhanced water retaining capacities of soil. The pre-sowing irrigation water requirement for wheat which is 75-100 mm is eliminated in the mulched fields (Sidhu et al 2015). Also, the surface retention of crop residues reduces soil moisture loss through evaporation in wheat crop by 35-45 mm (Lohan et al 2017; Sidhu et al 2015; Singh et al 2011). The benefit on enhanced water use efficiency is observed to be much higher. Singh et al (2018) reports the water savings of 3-11% while water use efficiency improves by 25% in wheat crop due retention of rice straw as mulch. Also, in the long-term, improvement in SOC improves the soil structure and reduces the run-off water. These savings are especially relevant for North West India where replenishment rate of ground water 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).

As discussed above, with a conservative estimate on water savings equivalent to 75 mm owing to avoided pre-sowing irrigation only in the mulched fields and 40 mm savings during the wheat crop growth in all the fields with mulching/mixing of rice straw, **total water savings in this season is estimated to be 2.5 billion litres as a result of this initiative.** Savings in each cluster are highlighted in the Table 7. Assuming four irrigation cycles, savings during the growth of wheat crop are approximately 13% of the total water requirement of wheat crop. Although farm-level data was being acquired from farmers at the time of writing this report, as noted on the supplementary material SM 6, 38-56% of farmers in two intervened villages in Ludhiana agreed on significant reduction in irrigation water requirement for the wheat crop.

Table 7. Estimated water savings across three rural clusters as a result of sustainable farming practices adopted by farmers

Water savings [million litres]	Nabha Cluster	Raikot Cluster	Samana Cluster
Pre-sowing (~75 mm)	319	403	52
Wheat Season (~40 mm)	802	807	129

Source: CII-CESD (2019) estimate based on Singh et al (2011), Sidhu et al (2015), Lohan et al (2017), Singh et al (2018) an farmer survey data

4.4.3 Reduced Instances of Weed and Avoided Chemical Inputs

Besides nutrient savings mentioned earlier in this section, near elimination of weedicide cost is found to be a key co-benefit of mulching the rice straw. This is one of the contributing factors for enhanced wheat yield in the mulched fields as described later in this section. Instances of weed in wheat crop are substantially reduced due to residue retention as mulch layer (mulching) and as a result, least disturbance in the top soil layers between tillage and sowing operations. Weeds have significantly grown in Punjab's rice-wheat monoculture due to intensification of agriculture and lack of crop rotation. Weed causes about 25-30% of productivity/yield losses in wheat crop (Singh et al 2016) and causes land degradation, impairs grain quality and substantially increase the cost of cultivation. Based on inputs from farmers, it is estimated that **farmers in intervened area saved INR 800-2400 per acre on weedicides[11] dependent upon specific field conditions for weed named Gullidanda or Phalaris Minor prevalent with the wheat crop in Punjab**. As per the group discussions with farmers and primary farming data (See Supplementary Material SM 6. for more details), farmers typically apply the weedicide 3-4 times depending on prevalence and recurrence of weed in the wheat field and a single spray of weedicide costs them approximately INR 800 per acre. Lesser chemical inputs also reverse the trend with soil and groundwater pollution, improving farmers well-being and livelihood in long-term.

4.4.4 Improved Livelihood and Climate Resilience

Table 8. Literature review of impact on yield of wheat crop as a result of in-situ application of rice straw

S.N.	Reported improvement in wheat yield	Source
1.	5-10% better yields recorded by PAU Scientists in happy seeder sown wheat fields during 2007-08	Kumar et al (2015)
2.	Average change of 2.2 % in the first year and 3.2% in the next two years in happy seeder sown fields across multiple sites in Punjab	Sidhu et al (2015)
3.	8% better yield in 2013-14 16% better yield in 2014-15 with extreme climate event (excess rainfall)	Aryal et al (2016)
4.	2-4% improvement in wheat yield or approx. 200 kg-wheat grain/ha with mulching using Happy Seeder & Super SMS fitted combine in Punjab	NAAS (2017)
5.	-0.05%, +2%, +3% wheat yield in three consecutive years with retention of 100% rice straw and 25% wheat straw	Kakraliya et al (2018)
6.	Yield increase between 200–500 kg/ha (equivalent to 4-9% improvement) in rice-wheat system in the Indo-Gangetic plains (IGP)	Ram et al (2018)
7.	Wheat grain yield by 7.3% compared to conventional tilling with rice straw removal with 100% rice straw retained as surface mulch for four consecutive years at PAU, Ludhiana	Thind et al (2019)
8.	9% improvement in wheat yield with residue retention & crop rotation for 6 years	Jat et al (2019)

Source: CII-CESD (2019) Analysis of secondary data

Reusing the straw in-field improves the system-wide performance of agricultural operations extending which goes beyond the nutrient recycling. As reported in the table 8, literature review indicates that the in-situ management of rice straw is estimated to improve 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 and Jat et al 2019) though the available literature also notes numerous examples where no substantial changes in yield are reported, particularly, in the initial years of adoption (Sidhu et al 2015, Ram et al 2018). This is especially due to

[11] This is a conservative estimate considering the cost of chemical inputs and labour cost. The figure is based on the preliminary findings from two villages (Refer SM 6.) in Ludhiana and may change based on more comprehensive assessment of farming practices, considering the full cropping cycle. These inputs were awaited at the time of writing this report.

immobilisation of Nitrogen by the Carbon in the initial phase as the C:N ratio of the rice as well as wheat straw varies widely between 70:1 to 100:1. This may cause Nitrogen deficiency in soil in the first year, in turn lowering the yields and increasing the demand for Nitrogen (Urea and DAP) in the first year by a very small amount. The trend reverses in few months as the carbon in paddy straw undergoes decomposition. This phenomenon was, in fact, very common in intervened areas and farmers expressed apprehensions and were advised to apply urea to affected crops (yellowing of wheat plants in first few months). Kakraliya et al (2018) reports the similar results i.e. -0.05%, +2%, +3% wheat yield in three consecutive years with retention of 100% rice straw and 25% wheat straw. From these discussions, it can be concluded that **although no significant yield improvement is expected in the first year, in consecutive years, crop yields are expected to undergo gradual improvement from 2% to 10%[12].**

Promotes climate adaptation of farming sector by reducing the impacts of extreme climatic events such as erratic rainfall or droughts (Watson et al 2019). It has been reported that mulch produced 40% higher root length densities compared to no mulch in lower layers (> 0.15 m) (Singh et al 2018). Recently, there has been increasing evidence on this. Aryal et al (2016) reports that during extreme climate induced event (excess) in 2014-15 in Haryana, 16% better yields observed in the wheat crop. Additionally, it has been observed in the intervened area that direct sowing with happy seeder (without cutting and spreading), makes the wheat seedlings and crop less prone to attacks by straw animals. This is due to the effect of blades of standing paddy stubble, left by combine harvester, which prevents animals from grazing on newly germinated wheat crop. **Promoted practices therefore enhance overall livelihood and well-being of farmers, by improving climate resilience of the crop and equipping them against the unpredictable weather events induced by climactic change**.

4.5 Assessment of Farmers' Behaviour

Farmers in intervened areas were asked about their motivations for burning and adopting solutions in the year 2018. Different reasons as ranked by farmers in Ludhiana and Patiala are presented in Figure 10 and 11 in their order of precedence.

It is observed that high labour cost involved in managing straw, unavailability of labour, simply the convenience are key factors in farmers continued preference for burning rice straw (See Figure 10.). According to famers' perception, other leading factors include lack of suitable tools in market, peer-pressure. Unavailability/affordability of tools, and lack of knowledge about better management practices are also responsible for farmer choice. Interestingly, these factors were found to be more or less in the same order of precedence in two districts.

[12] The actual field data on yield of wheat crop which is typically harvested during April-May was being acquired at the time of writing this report

Figure 10. Ranking of Reasons Why Farmers Burn Rice Straw

Rank	Nabha (Patiala)	Raikot (Ludhiana)
1	High Labour cost	Unavailability of Labour
2	Convenience	Convenience
3	Unavailability of Labour	High Labour cost
4	Lack of Suitable Tools in Market	Peer-pressure
5	Peer-pressure	Lack of Suitable Tools in Market
6	Unavailability of Tools for Renting	Unsure about Benefits of Alternate Practices
7	Unaffordability of Tools	Unaffordability of Tools
8	Unsure about Benefits of Alternate Practice	Unavailability of Tools for Renting
9	Weed & Pest Control	Weed & Pest Control

Source: CII-CESD (2019) Analysis of Farmer Survey Data

When asked about motivation to adopt new practices, farmers across different areas pointed to soil-health, air pollution & health, and peer-pressure as leading factors (See Figure 11). Hence it is proved that farmers in the **communication and behaviour change tools which were used to convince the farmer community for adopting zero burning approaches have been very successful**.

Figure 11. Ranking of Reasons Why Farmers Adopted Alternate Practices Instead of Burning Rice Straw in 2018

Rank	Nabha (Patiala)	Raikot (Ludhiana)
1	Soil Health	Soil Health
2	Air Pollution & Health	Air Pollution & Health
3	Peer-Pressure	Peer-Pressure
4	Fear of Penalisation	Religious Sentiments
5	Crop Yield Benefits	Fear of Penalisation
6	Religious Sentiments	Cost Effectiveness
7	Access to Tools	Access to Tools
8	Cost Effectiveness	Crop Yield Benefits
9	Organic Farming	Organic Farming

Source: CII-CESD (2019) Analysis of Farmer Survey Data

5. Key Challenges & Learnings

A huge demand-supply gap was observed in the year 2018 for in-situ management tools and the local manufacturers were unable to cater to the needs of farmers. Also, the cost of tools shot up by roughly 40% after announcement of the subsidy scheme. Many Farmer Producer Organisations (FPOs) or other private groups of farmers could not afford the subsidy as they were required to pay full up-front cost of these machines to the vendors and later available the subsidies. Although CIIF was able to procure the required machinery in consultation with farmers and fill the gaps in intervened areas, the programme suffered because of delays in arrival of required tools by manufacturers. This happened despite reliance on empanelled[13] as well as non-empanelled manufacturers in consultation with agricultural experts at PAU. Delayed supply of machinery may have affected the adoption of new tools/methods (especially with happy seeder) with farmers. Few tools which arrived late, were assembled at the field and lacked quality testing which subsequently leads to operational challenges to farmer on the field.

Another key concern with adoption of new tools for mulching/mixing rice straw was availability of high horse power (≥ 50 HP) tractors which is found to be extremely low for marginal to medium farmers (See Table SM 5.1). In addition to the farm implements, it is found that most of the new tools in the market, such as happy seeder and MB Plough, require high horse power tractors for operating them on the field. Although high horse power tractors were rented by CIIF to run the required number of tools, it remains key concern as numbers of such tractors are very limited in Punjab. Farmers ranked this as a key concern for adoption in future (See Figure 12).

Within the weeks of the sowing season, perception towards new technologies completely changed at the village level, although a very few farmers expressed concerns about germination time which is relatively longer under in-situ mulching methods compared to conventional methods. Germination time is understood to be the number of days when wheat seedlings become visible above the ground. It varies with the tool and is associated depth of sowing.

[13] Empaneled by government under the Central Subsidy Scheme

Figure 12. Key Concerns of Farmers for Utilising Rice Straw

Rank	Nabha (Patiala)	Raikot (Ludhiana)
1	Unavailability of High H.P. Tractor	Cattle do not like rice straw as feed
2	Cattle do not like rice straw as feed	Unavailability of High H.P. Tractor
3	Delayed Disbursements of Tool Subsidies	Minimum Financial Support
4	No Cattle for feeding straw	No Cattle for feeding straw
5	Minimum Financial Support	Delayed Disbursements of Tool Subsidies
6	No Subsidies for Needed Machinery	No Subsidies for Needed Machinery
7	High Operational/Rental Cost	High Operational/Rental Cost
8	Lack of Training/skilled Operator	Risk for Next Crop
9	Risk for Next Crop	Lack of Training/skilled Operator

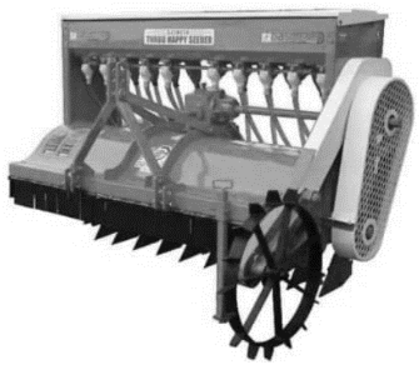
Source: CII-CESD (2019) Analysis of Farmer Survey Data

Unique challenge related to in-situ treatment of rice straw was experienced in the rural cluster of Nabha, where there are significant number of rice-potato farmers as opposed to predominantly rice-wheat monoculture. Soil conditions in the villages belonging to this cluster are found to be sandy or sand loamy which render the in-situ treatment using available tools, technically infeasible.

As highlighted in the Section 4.1, mixing or soil incorporation is the only workable solution for the potato farmers. But in the case of sandy or sand loamy soils, straw incorporation in the soil leads to soil disturbances to the extent that top fertile layer of soil is disturbed and as a result of which potato yields suffer. Therefore, no technically viable solutions are available to farmers as of now. Going ahead, this is expected to be a major concern as significant portion of farmers (~15% of all paddy farmers) in Punjab and Haryana are rice-potato farmers as opposed to predominant rice-wheat farming culture.

Besides the programme-level challenges described above, several tool-specific challenges were also experienced by farmer which are highlighted separately in the Box 2.

Box 2. Tool Specific Challenges Faced During Implementation



Happy seeder

a. Happy seeder can't be used on unleveled fields.
b. Large quantities of straw with paddy varieties will hinder sowing operation by happy seeder will lead to patches of non-germination of wheat.
c. With uneven spread of straw manually without the use of Super SMS will cause thick layer of mulch in some patches of the field which might hinder the sprouting of wheat.
d. Happy seeder requires bigger tractor with higher horse power to work properly.
e. The field settings and operation of happy seeder require constant attention and technical training (for proper field calibration)
f. Depth of sowing with happy seeder is more leading to longer germination times as it takes longer for seedlings to become visible on the ground

Rotavator

a. Rotavator can't work properly on standing straw and usually requires 2-3 runs in such cases. This results into higher maintenance cost due to breakdown of its blades.
b. Rotavator makes the soil harder with each operation and farmer may find it problematic in long-term.
c. Irrigation requirement of rotavator sown (incorporation of straw) fields is more, almost comparable to the burnt fields.
d. There is no significant reduction in the weed growth in the case of straw incorporation, compared to mulching.
e. Wheat plants are more likely to be affected by the wind due to lower depth of sowing

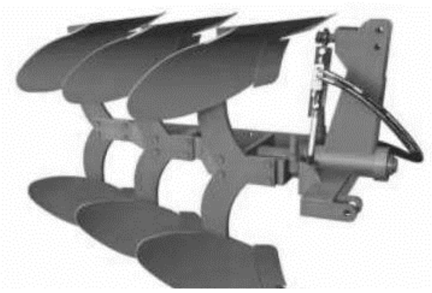
Super SMS

a. In most of the cases, cost of renting SMS attached combine harvester is found to be very high (incremental cost of INR 500-600) which is a major concern to the farmers
b. SMS causes a significant reduction in the field capacity of Combine leads and leads to higher fuel consumption
c. Farmers have raised apprehension about paddy yield being affected by the Super SMS attachment[14] and further developments will be required to address farmers' concerns
d. Farmers also reported excessive heaping of straw with super SMS at times which led to burning of heaps in these pockets.

[14] Super SMS is made available to farmers by the service providers of Combine Harvester and It is not clear at this stage whether this problem exists with particular models of super SMS/Combine Harvester in the market or applies across different models. Attaching Super SMS has been made mandatory for all combine harvesters by the Government of Punjab, though very few combines in the market are attached with Super SMS at present.

Mulcher

a. Mulcher is used to cut the standing stubble and form a uniform mulch layer of stubble on the field on which either happy seed or rotavator can used to sow wheat.
b. In case where the straw is moist, mulcher can't be used as the blades of mulcher will slip and will not effectively cut the standing straw.
c. There are cases where curved disk harrow is preferred over mulcher, for rotavator application.



Reversible MB Plough

a. MB Plough is used to incorporate straw back into the soil by rotating the top layer of the soil itself, as a result it increases the fertility of the soil under normal soil conditions and assists faster degradation of incorporated straw.
b. It requires high horse power tractor and associated diesel consumption is higher.
c. MB Plough can't be used in cases where the sub-soil is infertile or sandy.
d. MB Plough is works best in case of sowing of potato as potato can't be sown onto mulched soil

Source: CII-CESD (2019) Analysis based on Group Discussions with Farmers

6. Possibilities for the Future

As noted in the Section 4, air pollution and soil health are key motivations for farmers to switch to alternate practices substituting farm stubble burning. Local air quality monitoring will therefore be an important step from 2019 onwards and it is envisaged that low-cost monitoring strategies (such as sensor-based technologies and remote sensing data) can be utilised for monitoring in the village locations across Punjab and Haryana. This will be especially useful in measuring impact of this initiative by observing the changes in PM 2.5 concentrations in real-time which is the key pollutant emerging from crop-residue burning (see Section 4.1 and 4.2) and impacts air quality across IGP.

Also, the fields under new farming practices need to be consistently tested for key parameters such as nutrients concentrations, Soil organic carbon etc. Soil tests can only be conducted once there is not standing crop in the field and results for soil testing post the wheat harvesting season in April-May 2019 were awaited at the time of writing this report. A list of willing farmers has been prepared for collecting data on farming practices and various inputs (See SM 6. for sample data from two villages) in conjunction with the soil heath tests. For long term sustainability of this initiative, it will be crucial to collection this information for longer period of time (5-6 years) in order to establish long-term trends with changing practices and soil health.

It is observed that soil health card scheme is not implemented very well in Punjab, especially in the intervened areas. During the survey of more than 300 farmers, very few farmers could furnish details of latest soil health card. Hence, providing them with soil health card will enhance their capacity for science-based decision making and will also enable the research team as well as farmers understand and establish the important of sustainable farming practices in Western IGP where soil-health is severely degraded and natural resources such as ground water are rapidly depleting owing to unsustainable farming practices.

As pointed out in Section 4.4, more research is required to understand cost-effectiveness and environmental sustainability of ex-situ solutions. Huge environmental footprint and cost of baling and collection operations is a key concern (See Figure 9). Going ahead, selected village scale models can be identified and piloted, in order to assess their commercial viability. This is especially relevant for the case of rice-potato farms with infertile sub soils for whom in-field treatment is not technically feasible.

Figure 13. Example of Management Protocols & Good Farming Practices Proposed at Different Stages of Crop Growth. Photographs showing field operations and crop growth at different stages (October 2018-March 2019) in the intervened area of Raikot cluster in Ludhiana, Punjab

Source: CII-CESD (2019) Analysis

Management protocols and manuals need to be developed to ensure sustained adoption of new technologies by farmers. Farmers' apprehensions at different stages of operations as highlighted in the Figure 13 need to be addressed though timely action, clear delineation of responsibilities and real-time support.

1. Protocols for field staff need to be clearly laid out for timely procurement of tools and ensuring quality testing with manufacturers of tools. Similarly, service support from manufacturer is crucial for proper field calibration and problem free operation
2. Farmers' awareness on changing requirement of farm inputs is low. Farmers continue to flood the mulched field with water akin to conventional practice
3. Farmers see the nitrogen immobilization by plant carbon in initial phase of in-field treatment (See Section 4.4 d) as a warning sign while it is completely normal and temporary phenomenon that can be handled by applying additional Nitrogen
4. Protocols for farmer groups (FCSs/FPOs) for cleaning, storing and upkeeping of machinery
5. Training programmes for village volunteers
6. Technical know-how needs to be transferred to farmers by creating knowledge platform and similarly, farmers' feedback need to be transferred to R&D community working on new tools and techniques

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Supplementary Material

SM 1. Key Components of Crop Residue Management Initiative
SM 2. Farmer Survey Questionnaire
SM 3. Methods for Management of Farm Biomass
SM 4. Farmer landholdings in Punjab Districts
SM 5. Field Data on Methods and Tools under different Farming Practices
SM 6. Sample Field Data from Two Villages in Ludhiana

SM 1. Key Components of Crop Residue Management Initiative

1. **Behaviour change among farmers community**

   Constant dialogues with farmers and other local stakeholders were held to build awareness for adopting improved straw management approaches. Total 116 village meetings and rallies were held in 19 villages in Ludhiana and Patiala amounting to 5-7 such local meetings across each village in Ludhiana and Patiala. Local political factors play a big role in shaping farmers' interest in adopting non-burning practices. Local volunteers, functionaries of cooperative societies, village leaders played a key role for change in farmers attitudes. Gurudwaras were also in spreading the positive message in intervened villages.

2. **Financial support to farmer groups for procurement of farm tools**

   Based on assessed need in villages, total 73 tools were provided to farmer groups (including FPOs and FCSs) in 19 villages. Out of these, 49 of these were procured at the full cost while the rest were procured at subsidised cost under the Central Subsidy Scheme. Farmer groups took the responsibility of upkeeping these tools and ensuring that all farmers in the village get to use the machines on payment of a nominal rent. Farmer groups were additionally supported for renting high horsepower tractors to run these tools and for renting balers to clear those fields wherever in-situ application of straw was not technically feasible.

3. **Technical training and handholding**

   a. Farm level demonstrations and trainings were conducted in partnership with Punjab Agriculture University (PAU) and District Agriculture Departments with support of scientists from the PAU; Krishi Vigyan Kendra, Patiala; and Block Agriculture Offices
   b. Master trainers and village volunteers were trained at PAU and deployed to provide on the field technical handholding and support to farmers during the activity season.

4. **Participatory Monitoring on stubble burning through involvement of farmers and community volunteers**

   Village level "Nigrani Committees" were formed and these worked under the farmer co-operatives and maintained close contact with farmers offering them help for machinery support, technical handholding etc. These committees monitored cases of stubble burning in villages, if any, and undertook immediate community level remedial measures. A team of volunteers worked closely with the Nigrani Committees on this aspect.

SM 2. Farmer Survey Questionnaire (Jan 2019)

A. Socio-economic Identifiers

A 1. Name of respondent
A 2. Age (years)
A 3. Mobile/Telephone
A 4. Landmark
A 5. Gender
A 6. Relation to the Household
A 7. Education
A 8. Primary Occupation
A 9. Landholding details: Type of landholding, Acreage and Location
A 10. Average Annual Income from Agriculture
A 11. Average Annual Income from Other Sources
A 12. Standing Debt/Loan

B. Operational Landholdings and Cropping Pattern

B 1. Details of different Crop Varieties & Acreage under these
B 2. Choose your soil type
B 3. Latest soil health card data, if it exists
B 4. key recommendations made in the latest soil health card

C. Existing Practices and Behaviour

C 1. How do you manage post-harvest remains of the paddy crop?
C 2. Which tools did you use for different operations between harvesting of rice and sowing of next crop (wheat or potatoes) in this year?
C 3. What was the rent and operational cost paid for different field operations?
C 4. From where did you arrange these tools?
C 5. Which statements best describe your situation?
  C 3.1 I burn paddy-straw, because _ _ _
  C 3.2 I manage paddy-straw using alternatively, because _ _ _

D. Tools & Methods for Farm Biomass Management

D 1. Are you aware of the following tools for biomass management?
D 2. Did you use this tool in the last harvesting season?
D 3. Did you use this tool in the ongoing season?
D 4. Would you like to report any significant experience with this tool?
D 5. Will you prefer this tool in the next season?
D 6. Are you aware of the subsidy scheme on the following tools?
D 7. How many tools were applied for subsidy this year, individually and in group?
D 8. How many tools did you receive individually or in group?
D 9. Has the applied subsidy been released to you or farmer group?

E. Willingness to Manage Farm Biomass

E 1. How often are you willing to mulch the rice-straw in the field?
E 2. At what rate are willing to sell the rice straw, provided that the industry agrees to lift it from the field within 15 days from harvesting?

E 3. Rice-straw can also be converted into useful products at the community or individual level. Are you aware of the following methods?

E 4. What are the key challenges for adoption of on-field management methods (Prali-char or Biochar; Biogas; and Composting of rice straw)?

F. Shared Assets

F 1. Are there farmer co-operative or groups active in/for your village?

F 2. If yes, do you have a membership to this organisation?

F 3. Are you an active member of this organisation?

F 4. How many of the below equipment do you own: individually, with family members and with farmer co-operative and other farmer groups?

G. Inputs on Long Term Actions for Biomass Management

G 1. Have you tried any of these alternatives to rice/paddy in the past?

G 2. What are the major factors affecting your choice of listed alternatives?

G 3. What are your key concerns for utilising rice straw?

G 5. According to you, what would work in the future for curbing the practice of stubble burning?

H. Health Survey

H 1. Do you or does any of your family members have/has any breathing problem?

H 2. If yes, how long have you/your family member had a lung problem or breathing problem (e.g., asthma and emphysema)?

H 3. How many persons in your family have a limitation due to a lung/breathing problem?

H 4. Are you/they taking any treatment for the mentioned[15] (open-ended) lung problems?

H 5. If yes, please provide information on: How long ago the treatment started? How much did you save on your health expenditure, if any, compared to the last year in the period of October and November?

H 6. Do you or your family members have any symptoms/diseases related to the heart?

H 7. List household members that have died in the last five years, with information on-

a. Cause of death if known
b. Any respiratory problems
c. Length of sickness prior to death

H 8. What is the amount of time the you spend outside the house, overall activity and what are your main outdoor activities?

H 9. How would you rate the overall air quality in your area now compared to last year?

H 10. What do you think are other major causes of air pollution in your area?

*****

[15] Wheezing=1, Tightness of chest=2, Shortness of breath=3 Rapid breathing=4, Eczema=5 Hay Fever=6, Skin Irritation=7, Eye Irritation=8, Headache=9, Dizziness=10, Spasmodic episodes of cough=11, Repeated attacks of cold=12, Other _ _ _ =13

SM 3. Methods Adopted by Farmers for Management of Rice Straw

Table SM2.1 Methods for Managing Rice Straw along with Key Steps and Tool Combinations

S.N.	Farming Practice	Key steps and accompanying farm implements[1]
Conventional Methods Preceded by Complete Burning of Crop Residue		
I.	Complete Burning	1. Harvesting rice a. Combine harvester 2. Burning & watering[2] 3. Tilling & sowing wheat/potato a. HD[3] + Cultivator + Leveller+ Zero-till/Potato planter b. Rotavator + Seed drill[4]/Potato planter
Alternate Methods Promoted as Substitute to Burning Crop Residue		
II.	Mulching	1. Harvesting rice a. Combine harvester (CH) 2. Cutting & spreading[5] (optional) a. Super SMS (attached to CH)[6] b. Mulcher/Cutter-cum-spreader[7] 3. Tilling & sowing wheat/potato a. Happy seeder
III.	Mixing or Soil-incorporation	1. Harvesting rice a. Combine harvester 2. Cutting & spreading a. Super SMS (CH)[6] b. Mulcher/Cutter-cum-spreader[7] 3. Soil incorporation & sowing wheat/potato a. Rotavator + Seed drill (SD)[4]/potato planter b. MB Plough + Rotavator + SD[4]/potato planter
Other Alternate & Less Common Strategies Adopted by Farmers		
IV.	Baling/Collection & Evacuation	1. Harvesting rice a. Combine harvester 2. Cutting a. Cutter b. Rotary slasher 3. Rice Straw Collection c. Raker & baler 4. Sowing d. Rotavator + SD[4]/potato planter
V.	Partial burning & in-situ treatment[8]	1. Harvesting rice a. Combine harvester 2. Partial Burning & watering (depending on field conditions)[2] 3. Tilling & sowing b. Partial mixing: Rotavator+SD[4]/potato planter c. Partial mulching: Happy seeder

Source: CII-CESD (2019) Analysis based on the Field Data

Note:

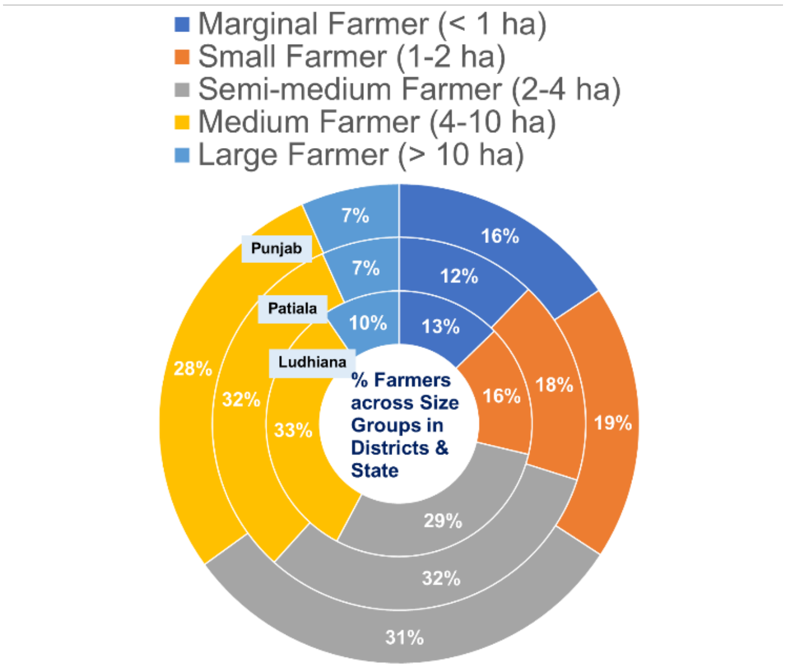
1. All the steps listed above (in bullets under column 4) are preceded by harvesting operation with the combine harvester. As presented in this table, different steps in the process can be implemented with the different combinations of tools which are further elaborated in the table….
2. Burning of crop residue on the field is usually followed by watering of the field.
3. HD stands for Harrow Disk, commonly used for tilling operation in Punjab under the conventional practices

4. Rotavator is either available as standalone tool or as Rotavator-cum-Seed drill, with the seed drill attached.
5. Cutting and spreading is optional for mulching the straw and as listed under the technique III-A, field with standing stubble can be sown directly, eliminating the need for cutting and spreading
6. Super SMS is attached to the combine harvester and eliminates the need for a separate operation for cutting and spreading the straw but deceases the field capacity for combine harvester operation
7. Mulcher/Cutter (or cutter-sum-spreader) are attached to tractor requiring separate step for cutting and spreading operation
8. Partial burning is technology hybridisation of complete burning and soil-incorporation

SM 4. Farmer landholdings in Punjab Districts

In Punjab, the farmer landholdings, which are categorised as marginal (<1 ha) and small (1-2 ha) are observed to be more 35% (< 2 ha) of total farmers as per the Information from Census 2011 (See Figure SM3.3). As per the same source, the figure is slightly below the state average in both Ludhiana and Patiala at ~30% whereas the large farmer landholdings (>10 ha) vary from 7-10% in Patiala and Ludhiana. The semi-medium to medium scale farmers in both the districts constitute about ~60% of all farmers.

Figure SM 4.1 Agricultural Landholdings Classified into Different Size Groups in Districts: Ludhiana, Patiala; and entire Punjab as per the Agriculture Census 2011



Source: CII-CESD (2019) Representation of the Agricultural Census (2011) Data

SM 5. Field Data on Methods and Tools under different Farming Practices

Table SM 5.1 Field data on various tools as utilised for different operations under various practices

Farm Implement/ Machinery Units-	Practices (See Table SM2.1)	Power Requirement [Horsepower]	Fuel (diesel) Consumption [Litre/acre]	Rental cost* [INR/acre]	Demonstrated Field Capacity [acre/day]	Note
Harvesting						
Combined Harvester (CH)	Conventional; In-situ; Baling	…..	8-10	1100-1250	15-20	• Rental cost on acreage basis as charged to farmers by private service providers of agricultural tools/machinery is INR 1100-1250 /acre. • The fuel and labour costs are covered in this rental cost. • Field capacity: 2-3 acres/ hour (20-30 min./ acre)
Cutting and Spreading						
Super-SMS	In-situ	CH ≥ 75 hp	4-5	350-650	10-15 (CH with Super SMS)	• Rental cost and fuel consumption for super SMS as listed here is incremental rental cost and fuel consumption in addition to rent for combine harvester captured in the row above • Lower field capacity with Super SMS (30-45 min./acre)
Chopper/ Cutter-cum-spreader	In-situ, Baling	T: 30-40 hp	3	157	20	• Rental cost on time basis: INR 1000-1200/day as charged to farmers by farmer co-op societies • Field capacity: 3-4 acre/hour (15-20 min./ acre)
Mulcher	In-situ	T ≥ 50 hp	4-6	111	8-10	• Rental cost on time basis: INR 800-1200/day as charged to farmers by farmer co-op societies • Field capacity: ~1 acre/hour
Mixing/ Soil Incorporation						
Reversible MB Plough	In-situ	T > 50 hp	9-12	100	8	• Rental cost on time basis: INR 800-1200/day as charged to farmers by farmer co-op societies • Field capacity: ~1 acre/hour
Rotavator	Conventional; In-situ; Baling	T ~ 50 hp	6-8	137	8	• Rental cost on time basis: INR 1000-1200/day • Field capacity: ~1 acre/hour
Tilling & Levelling (Field preparation)						

Harrow Disk (HD)	Conventional; Baling	T ~ 40 hp	3-5	37	15	• Rental cost on time basis: INR 500-600/day as charged to farmers by farmer co-op societies • Field capacity: ~2 acre/hour (30 min./acre)
Cultivator	Conventional; Baling	T ~ 40 hp	3-5	37	15	• Rental cost on time basis: INR 500-600/day as charged to farmers by farmer co-op societies • Field capacity: 2-3 acre/hour (20-30 min/acre)
Leveller (or Suhanga)	Conventional; Baling	T ~ 40 hp	3-5	37	15	• Rental cost on time basis: INR 500-600/day as charged to farmers by farmer co-op societies • Field capacity: 2-3 acre/hour (20-30 min/acre)
Sowing						
Zero Till (ZT) Seed Drill	Conventional; Baling	T ~30 hp	2-3	68	8-11	• Rental cost on time basis: INR 600-700/day as charged to farmers by farmer co-op societies • Field capacity: ~1.33 acre/hour (~45 min./acre)
Rotavator-sum-Seed Drill	Conventional; In-situ; Baling	T > 50 hp	6-8	187	8	• Rental cost on time basis: INR 1500/day as charged to farmers by farmer co-op societies • Field capacity: ~1 acre/hour
Happy seeder	In-situ	T ≥ 50 hp	6-8	162	8	• Rental cost on time basis: INR 1100-1500/day as charged to farmers by farmer co-op societies • Field capacity: ~1 acre/hour
Baling						
Baler + raker		…..	6-7 (baler) 3-4 (raker)	1500-2000	15	• Rental cost on acreage basis as charged to farmers by service provider is INR 1500-2000/acre. • This rental cost also includes the fuel and labour costs for combine harvester operation • Field capacity: ~2 acre/hour (~30 min./acre)

Source: CII-CESD (2019) analysis based on consultations with Farmer Groups (Farmer Producer Organisations, Farmer Co-operatives), Machines Operators, and Private Service Providers in intervened areas in Ludhiana and Patiala

Notes:

1. Under second column for power requirement- 'CH' denotes the combine harvester and 'T' demotes the tractor.
2. The key assumption is the maximum 6-8 hours of operation in a day. Moisture levels in the field are ideal for farming operations only in this stipulated period in the months of October and December.
3. The rental cost (*) charged by private service providers, for combine harvesting and baling, already includes the fuel and labour cost components. This is unlike the rental costs for farm implements as given in the table where fuel and labour charges not covered in rent. Cost of operating various farm implements was assumed to be INR 300/hour which includes the tractor rent and associated labour charges. It therefore serves as a proxy for labour changes and cost of tractor for running various farm implements.
4. Happy seeder not only require high HP of tractor but also a heavy tractor which can pick it up and does not incline while working.

Table SM 5.2 Method-Wise Information on Cost, Operational Days and Fuel Consumption											
TYPE OF METHOD		S. N.	Tool Configuration	Rental Cost for harvesting & sowing operations [INR/acre]	Tractor & Labour cost for post-harvesting operations [INR/acre]	Fuel cost to farmer [INR/acre]	Total cost [INR/acre]	Total Fuel Consumption (post-harvest operations) [Litre/acre]	Minimum hours of mechanised operations [hour/acre]	Period between harvesting & sowing for one-acre field [days]	Germination time [days]
CONVENTIO-NAL METHODS (PRECEDED BY COMPLETE BURNING)		1.	a. Combine harvester b. Disk Harrow (x2) c. Cultivator (x2) d. Leveller (x2) e. ZT Seed Drill	1390	1200	1400	3990	28 (20)	4.5	3-4	7-10
CONVENTIO-NAL METHODS (PRECEDED BY COMPLETE BURNING)		2.	a. Combine harvester b. Rotavator-cum-SD	1287	300	420	2007	14 (6)	1.5	1-2	7-10
ALTERNATE METHODS	MULCHING	1.	a. Combine harvester + Super-SMS b. Happy seeder	1762	300	420	2482	16 (6)	1	1	12-15
ALTERNATE METHODS	MULCHING	2.	a. Combine harvester b. Happy Seeder	1262	300	420	1982	14 (6)	1	1	12-15
ALTERNATE METHODS	MULCHING	3.	a. Combine harvester b. Mulcher/Cutter c. Happy seeder	1373	600	700	2673	18 (10)	2.5	2	12-15
ALTERNATE METHODS	MIXING	1.	a. Combine harvester b. Rotavator cum-SD (x2)	1474	600	1120	3194	24 (16)	2.5	2	7-10
ALTERNATE METHODS	MIXING	2.	a. Combine harvester b. Mulcher c. Rotavator-cum-SD	1398	600	840	2838	20 (12)	2.5	2	7-10
ALTERNATE METHODS	MIXING	3.	a. Combine harvester b. Mulcher c. MB Plough d. Rotavator-cum-SD	1498	900	1330	3728	27 (19)	3.5	2	7-10
BALING (COLLECTION & EVACUATION OF BIOMASS)		1.	a. Combine harvester b. Cutter c. Raker + Baler d. Disk Harrow (x2) e. Cultivator (x2) f. Leveller (x2) g. ZT Seed Drill	2890	1200	1400	5490	37 (20)	5	3-4	7-10

	2.	a. Combine harvester b. Cutter c. Raker + Baler d. Rotavator-sum-SD	2787	300	420	3507	21 (6)	2	1-2	7-10

Source: CII-CESD (2019) analysis based on consultations with Farmer Groups (Farmer Producer Organisations, Farmer Co-operatives), Machines Operators, and Private Service Providers in intervened areas in Ludhiana and Patiala

Notes:

1. Under conventional tillage practice (Method 1 in the above table), two runs of farm implements intended for tilling and leveling (disk harrow, cultivator and leveler) are assumed on average in consultation with farmers in Ludhiana and Patiala.
2. Rotavator cum seed drill fuel consumption varies depending on whether the straw is burnt (lower), or it is mixed in the soil (higher). Lower and upper range given in table represent these two different scenarios were accordingly used for calculating fuel consumption under different methods.
3. Representative baler used for this analysis is most commonly used baler in Punjab which makes rectangular bales of about 30-35 kg and a high horsepower tractor is required for operating this baling machine which is provided by the private service provider. There are other less common models of balers available in market including the small capacity balers which work with smaller tractor and very high capacity balers making round bales weighing few hundreds to one quintal.
4. A period of 3-4 days is required in case of conventional practice involving burning of crop residue. Operation involves cutting the straw, letting it dry for two sunny days, burning followed by watering to maintain the appropriate soil moisture for sowing next crop.
5. Germination time is defined as the number of days between sowing of wheat seeds and a visible sprouting of wheat above the soil.
6. Some of the farmers adopted straw incorporation into their soil with rotavator for this two time use of rotavator one for incorporation and one for sowing.

SM 6. Sample Field Data from Two Villages in Ludhiana

	Village – Govindgarh, Ludhiana *Total farmers in the village – 141* *Paddy Area – 1000 acres* *Estimated zero burning – 832 acres (86%)*		Village – Kalsan, Ludhiana *Total farmers in the village – 381* *Paddy Area – 700 acres* *Estimated zero burning – 336 acres (48%)*	
Survey dates	15th and 21st Jan 2019		31st Jan 2019	
Sample size of the survey (randomly selected)	34 farmers		26 farmers	
Soil type prevalent in the village	Medium to hard soil		Medium to hard soil	
Paddy variety sown by farmers	Pusa-44 *(yield 30Q/ acre; straw production 2.5 tonnes/acre)*		Pusa-44	
Total paddy acreage by farmers surveyed	561.5 acres		270.5 acres	
Extent of adoption of Burning/ no burning approach	**Burning**	**No burning**	**Burning**	**No burning**
	9 farmers adopted traditional practice of burning	25 farmers adopted zero burning practice	5 farmers adopted traditional practice of burning	21 farmers adopted zero burning practice
Area under burning/ no burning	100.5 acres (of burned area including 78 acres partially burned)	461.5 acres (of zero burning area with 67.5acres of under mulching (happy seeder, mulcher and 357.5 acres of incorporation by rotavator)	54 acres (of burned area including 26 acres partially burned)	216 acres (of zero burning area with 3 acres mulched Happy seeder and 170 acres of incorporation by rotavator)
Paddy Harvesting Cost	Rs 1500/acre	Rs 1550/acre	Rs 1570/acre	Rs 1640/acre
Processes for land preparation	All the farmers used rotavator (burning – watering - land preparation & Sowing using rotavator	7 farmers used happy seeder and mulcher, 18 farmers used rotavator seed drill (for straw incorporation & sowing)	All the farmers used rotavator	1 farmer used happy seeder rest 20 farmers used rotavator seed drill
Time taken for land preparation and sowing	**7 days (1-2 Days Burning+ 3-4 Days Watering + 1-2 days machine operations)**	**2-3 days**	**7 days**	**2-3 days**
Average wheat sowing cost	Rs 1400/acre	Rs 1320/acre	Rs 1400/acre	Rs 1240/acre
Total cost of paddy harvesting + wheat sowing	**Rs 2900/acre**	**Rs 2870/acre**	**Rs 2970/acre**	**Rs 2880/acre**

Weedicide application till the time of survey	**3 times (Cost Rs 2400)**	**nil**	**3 times (Cost Rs 2400)**	**1-2 times (Cost Rs 800 to Rs 1600)**
Irrigations till the time of survey	**2**	**1**	**2**	**1**
Farmers' preference for next year	3 farmers (who have burnt fields) have tried happy seeder in small patches, where the result has been good, and they will adopt no burning practice next season.	All 7 farmers prefer happy seeder for next year. 4 more farmers are ready to try it next season. Other farmers are undecided as of yet.	2 farmers who burnt stubble this year said they liked the result of HS and will try next year. 3 farmers are undecided as of yet	Farmers are satisfied with HS field and 10 will try it next year.
Farmer perception on expected benefits of improved crop residue management				
On irrigation	52% farmers agreed that irrigation water requirement decreases with non- burning practices		38% farmers agree that irrigation water requirement decreases with non-burning practices	
On reduced need for fertilizers	29% farmers agreed that using non-burning practices need of fertilizer is reduced		27% farmers agree by using zero burning practices need of fertilizer is reduced	
On reduced incidence of weeds	56% farmers agree that the weed growth will be reduced by using non burning practices		30% farmers agree that the weed growth will be reduced by using zero burning practices	

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