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How can Punjab Increase the Adoption of Crop Residue Management Methods?

Survey Insights from 11 Districts of the State

Kurinji Kemanth, Ramandeep Singh, and Sneha Maria Ignatious

Report | July 2024

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Council on Energy, Environment and Water
ISID Campus, 4 Vasant Kunj Institutional Area
New Delhi – 110070, India
+91 11 4073 3300

info@ceew.in | ceew.in | @CEEWIndia | ceewindia

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Solving stubble burning requires a holistic approach encompassing in-situ and ex-situ crop residue management techniques, crop diversification and awareness drives for their wider and sustained adoption.

Image: iStock

अरविन्द नौटियाल
सदस्य-सचिव
Arvind Nautiyal
Member-Secretary

सत्यमेव जयते

राष्ट्रीय राजधानी क्षेत्र और
निकटवर्ती क्षेत्रों में
वायु गुणवत्ता प्रबंधन आयोग
Commission for Air Quality Management in National Capital Region and Adjoining Areas

Date: 25th June 2024

FOREWORD

While Crop residue management (CRM) has emerged as a critical challenge, it also serves as an opportunity for Indian agriculture landscape. For decades, the practice of burning crop residue has resulted in concerns of public health and environment degradation. The Government of India has initiated a series of efforts in this endeavour, including promoting in-situ CRM through a central sector scheme, providing financial assistance for alternative ex-situ uses of crop biomass, prohibiting crop residue burning practices and conducting awareness drives for wider adoption of zero-burn CRM methods.

The Commission for Air Quality Management in the National Capital Region and Adjoining Areas (CAQM) is actively working towards better coordination, research, identification and resolution of issues like crop residue burning and other issues that affect air quality index. The Commission has been periodically bringing out directions and guidelines to prevent and control crop residue burning in the northwestern states of India. In addition, the Commission has been deliberating upon the issue in a series of meetings held with key stakeholders, including the state governments and State Pollution Control Boards of the NCR states, Punjab and Delhi Pollution Control Committee (DPCC) and various knowledge institutions. We recognise that a holistic approach is necessary, encompassing in-situ management techniques, promotion of ex-situ biomass utilisation for fodder, energy, fuel, compost, other miscellaneous commercial applications etc and fostering farmer awareness through capacity-building programmes.

This CEEW report documents the progress made under various government initiatives, including the central sector scheme and the on-ground status of Punjab's stubble management journey. We are encouraged by the increasing adoption of sustainable residue management practices by farmers. However, we also note the gaps that still remain. This report should serve as a roadmap for continued efforts, outlining key focus areas like advancements in paddy diversification, market development for residue-based products and service applications and strengthening custom hiring centres in the battle against crop residue burning.

I compliment CEEW for releasing this report and hope that its findings will foster collaborative efforts amongst the state governments, research institutions, industry stakeholders and farmers toward a future where crop residue is no longer a source of pollution but a valuable resource for a sustainable and prosperous agricultural sector.

(Arvind Nautiyal)

CAQM

17 वीं मंजिल, जवाहर व्यापार भवन (एस.टी.सी. बिल्डिंग), टॉलस्टॉय मार्ग, नई दिल्ली-110001
दूरभाष : 011-23701197, ई-मेल : arvind.nautiyal@gov.in

17th Floor, Jawahar Vyapar Bhawan (STC Building), Tolstoy Marg, New Delhi-110001
Tel. : 011-23701197, E-mail : arvind.nautiyal@gov.in

We surveyed ~1500 farmers in Punjab to assess the state's crop residue management practices.

Image: NYAS Research

About CEEW

The **Council on Energy, Environment and Water** (CEEW) is one of Asia's leading not-for-profit policy research institutions and among the world's top climate think tanks. The Council uses **data, integrated analysis, and strategic outreach to explain — and change — the use, reuse, and misuse of resources**. The Council addresses pressing global challenges through an integrated and internationally focused approach. It prides itself on the independence of its high-quality research, develops partnerships with public and private institutions, and engages with the wider public. CEEW is a strategic/ knowledge partner to 11 ministries for India's G20 presidency.

The Council's illustrious Board comprises Mr Jamshyd Godrej (Chairperson), Dr Anil Kakodkar, Mr S. Ramadorai, Mr Montek Singh Ahluwalia, Dr Naushad Forbes, and Dr Janmejaya Sinha. The 300+ strong executive team is led by Dr Arunabha Ghosh. CEEW was certified a **Great Place To Work®** in 2020 and 2021. It has also repeatedly featured among the world's best managed and independent think tanks.

In over 13 years of operations, The Council has engaged in over 450 research projects, published 380+ peer-reviewed books, policy reports and papers, created 190+ databases or improved access to data, advised governments around the world 1400+ times, promoted bilateral and multilateral initiatives on 130+ occasions, and organised 540 seminars and conferences. In July 2019, Minister Dharmendra Pradhan and Dr Fatih Birol (IEA) launched the CEEW Centre for Energy Finance. In August 2020, Powering Livelihoods — a CEEW and Villgro initiative for rural start-ups — was launched by Minister Piyush Goyal, Dr Rajiv Kumar (then NITI Aayog), and H.E. Ms Damilola Ogunbiyi (SEforAll).

The Council's major contributions include: Informing India's net-zero goals; work for the PMO on accelerated targets for renewables, power sector reforms, environmental clearances, *Swachh Bharat*; pathbreaking work for India's G20 presidency, the Paris Agreement, the HFC deal, the aviation emissions agreement, and international climate technology cooperation; the first independent evaluation of the *National Solar Mission*; India's first report on global governance, submitted to the National Security Advisor; support to the National Green Hydrogen and Green Steel Missions; the 584-page *National Water Resources Framework Study* for India's 12th Five Year Plan; irrigation reform for Bihar; the birth of the Clean Energy Access Network; the concept and strategy for the International Solar Alliance (ISA); the Common Risk Mitigation Mechanism (CRMM); India's largest multidimensional energy access survey (ACCESS); critical minerals for *Make in India*; India's climate geoengineering governance; analysing energy transition in emerging economies, including Indonesia, South Africa, Sri Lanka, and Viet Nam. CEEW published *Jobs, Growth and Sustainability: A New Social Contract for India's Recovery*, the first economic recovery report by a think tank during the COVID-19 pandemic.

The Council's current initiatives include: State-level modelling for energy and climate policies; consumer-centric smart metering transition and wholesale power market reforms; modelling carbon markets; piloting business models for solar rooftop adoption; fleet electrification and developing low-emission zones across cities; assessing green jobs potential at the state-level, circular economy of solar supply chains and wastewater; assessing carbon pricing mechanisms and India's carbon capture, usage and storage (CCUS) potential; developing a first-of-its-kind Climate Risk Atlas for India; sustainable cooling solutions; developing state-specific dairy sector roadmaps; supporting India's electric vehicle and battery ambitions; and enhancing global action for clean air via a global commission 'Our Common Air'.

The Council has a footprint in over 20 Indian states, working extensively with 15 state governments and grassroots NGOs. Some of these engagements include supporting power sector reforms in Uttar Pradesh, Rajasthan, and Haryana; energy policy in Rajasthan, Jharkhand, and Uttarakhand; driving low-carbon transitions in Bihar, Maharashtra, and Tamil Nadu; promoting sustainable livelihoods in Odisha, Bihar, and Uttar Pradesh; advancing industrial sustainability in Tamil Nadu, Uttar Pradesh, and Gujarat; evaluating community-based natural farming in Andhra Pradesh; and supporting groundwater management, e-auto adoption and examining crop residue burning in Punjab.

Nearly half of the in-situ practicing farmers followed partial burning of paddy residue before using the in-situ CRM machines in Kharif 2022.

Image: Kurinji Kemanth/CEEW

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Putting an end to crop residue burning could avert an economic loss of USD 120 million annually in Punjab (Chakrabarti et al. 2019).

Image: Kushal Kamanth/CEEW

Executive summary

India's food grain production has nearly tripled from 115.6 million tonnes (Mt) in 1960–61 to 329.6 Mt in 2022–23, with improved access to modern agricultural technologies driven by the Green Revolution (Deshpande et al. 2023). However, this heightened production has resulted in unsustainable crop residue management (CRM) strategies, such as stubble burning (Khundrakpam and Sarmah 2023). Of the 754 Mt of crop biomass produced annually, nearly 228 Mt remain as surplus after being utilised for processes such as roof thatching and cattle bedding; the majority of it is burnt (Sardar Swaran Singh National Institute of Bio-Energy n.d.). The practice of burning is prominent in northern states such as Punjab, where rice–wheat farming dominates. Factors contributing to this longstanding practice include the paddy–wheat cropping system, cultivation of long-duration paddy varieties, mechanised harvesting that leaves standing crop stubble in the field, labour scarcity and the lack of a viable market for crop residue (Kurinji and Prakash 2021).

Exposure to intense stubble burning increases the risk of acute respiratory problems threefold.

Exposure to intense stubble burning increases the risk of acute respiratory problems threefold (Chakrabarti et al. 2019). Atmospheric modelling studies estimate that during the peak burning, stubble burning contributes up to 30 per cent of post-harvest PM 2.5 levels in the Delhi National Capital Region and surrounding areas (Khan et al. 2022; Kurinji, Khan, and Ganguly 2021). Recognising the health impacts of stubble burning, states such as Punjab have adopted several measures, including the promotion of short-duration paddy varieties to extend the stubble management window, subsidies for CRM machines, and financial incentives for industries to create a market for biomass (PIB 2023). The existing stock of Super Seeders (43,452 units) and Happy Seeders (13,560 units) – the two most prominent CRM machines – is sufficient to cover 100 per cent of the paddy fields in Punjab if deployed at maximum capacity. However, barriers to timely access to CRM machines and their inflated operational charges, coupled with misperceptions over reduced yields and pest attacks on wheat sown using in-situ CRM machines, have resulted in the lower adoption rate of zero-burn residue management (Kurinji and Prakash 2021; Prakash and Singh 2022).

Putting an end to crop residue burning could avert an economic loss[1] of USD 120 million annually in Punjab (Chakrabarti et al. 2019). This requires timely deployment and widespread adoption of CRM methods at a rapid scale. To obtain a granular view of the preferred paddy variety and CRM methods, along with farmers' experiences with using them, we conducted a survey of 1,478 farmers from 11 districts of Punjab between March and May 2023. The selected districts – Amritsar, Bathinda, Fatehgarh Sahib, Fazilka, Firozpur, Gurdaspur, Jalandhar, Ludhiana, Patiala, Sangrur, and SBS Nagar – collectively accounted for about 58 per cent of

1. Economic value of disability-adjusted lives saved per year by eliminating the risk factor.

Kharif farm fires reported in Punjab in 2022. The survey aimed to answer three key questions:

- How can Punjab achieve paddy varietal diversification?
- To what extent has the increase in CRM machines resulted in reduced open burning of farm waste, and what factors can explain the continued gaps?
- Can ex-situ methods gain traction among Punjab's farmers?

The government-promoted short duration variety PR-126 is the most sought after paddy variety, but it is in short supply.

We employed a multi-stage stratified sampling method to mirror Punjab's farming population. To complement the findings, we conducted interviews with staff from agricultural departments and Krishi Vigyan Kendras (KVKs) during the analysis phase. This survey provides a multidimensional perspective on the state of CRM in Punjab and highlights multiple nuances associated with the sustained adoption of CRM methods. In response to another smoggy winter in 2023, the National Green Tribunal directed Punjab to prepare a time-bound action plan and implement phase-wise preventive measures from 1 January to 1 September 2024. Through this study, we aim to inform the union and Punjab governments of the challenges farmers face on the ground, and recommend policy measures to control stubble burning in the current and upcoming seasons.

A. Key findings

How did cropping preferences change?

Promoted by the government, the demand for short-duration[2] paddy varieties is on the rise

- The notable trend is the growth in acreage of short-duration varieties, increasing from 32.6 per cent in 2012 to 69.8 per cent in 2021 (Dhillon and Gill 2022). In 2022, nearly 66 per cent of surveyed farmers grew short-duration Parmal rice (PR) varieties. PR 126 is the most sought-after variety, grown by 57.7 per cent of PR growers), but short in supply.

High-burn districts continue to grow PUSA 44

- Over 36 per cent of surveyed farmers grew PUSA 44[3] in Kharif 2022 due to its high yield. High- and medium-burn districts, such as Sangrur and Ludhiana, have the highest proportion of PUSA growers. Though farmers' preferences are driven by PUSA 44's higher yield, current agricultural subsidies (for electricity and fertiliser) lead them to overlook the crop's implications on agricultural input use (Joshi et al. 2018; Dhillon and Gill 2022). Considering the environmentally detrimental traits of PUSA 44, the government de-notified the variety in October 2023. However, it remains in circulation primarily through private seed dealers.

Have government efforts influenced the adoption of in-situ CRM methods in Punjab?

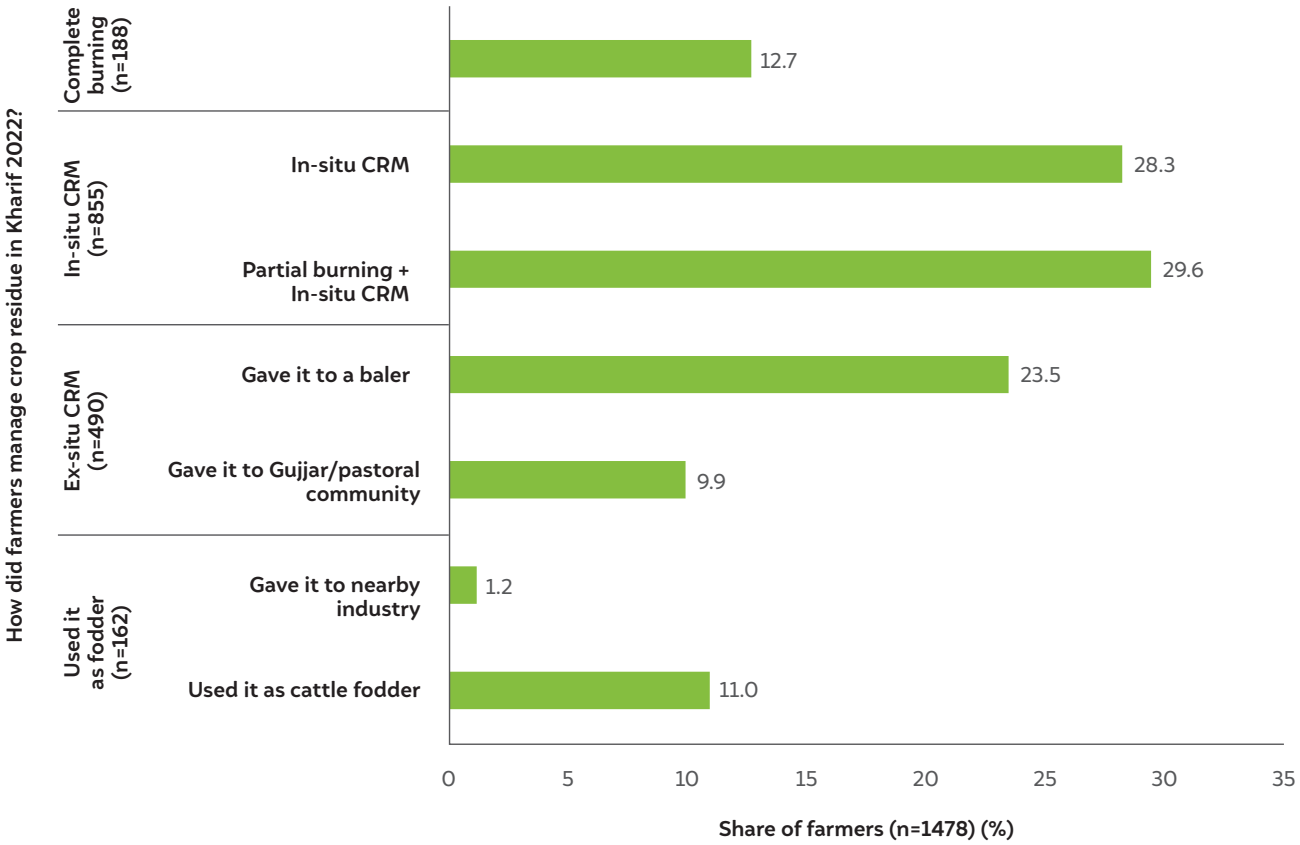
Despite adequate machinery, fires are not entirely addressed

- Nearly 13 per cent of the surveyed farmers burned their straw completely during Kharif 2022 (Figure ES1). The practice of burning was more prevalent among medium and large farmers than small and marginal farmers, who feared receiving financial penalties and red entries in the revenue records; the consequences of non-compliance had become more stringent in the post-COVID years.

2. Farmers get a longer window for scientific paddy stubble management while growing short-duration varieties.
3. PUSA 44 is infamous for its long crop duration, excess straw generation, and high agricultural input (fertiliser, pesticides, and water) consumption (J. M. Singh et al. 2022).

- Of the 58 per cent of farmers who had adopted various in-situ technologies such as the Super Seeder, nearly half of them (30 per cent) practised partial burning before utilising the CRM machine for efficient operation and pest control (Figure ES2). Rectifying partial burning requires the use of a combine harvester equipped with a Super Straw Management System (SMS) capable of cutting and spreading straw uniformly across the field. Despite the government's mandate for the compulsory use of the Super SMS, 64 per cent of the farmers refrained from using it due to its unavailability and high operational costs.

Figure ES1 Nearly half of the in-situ CRM machine users burned the loose straw before using the machine



Source: Authors' analysis

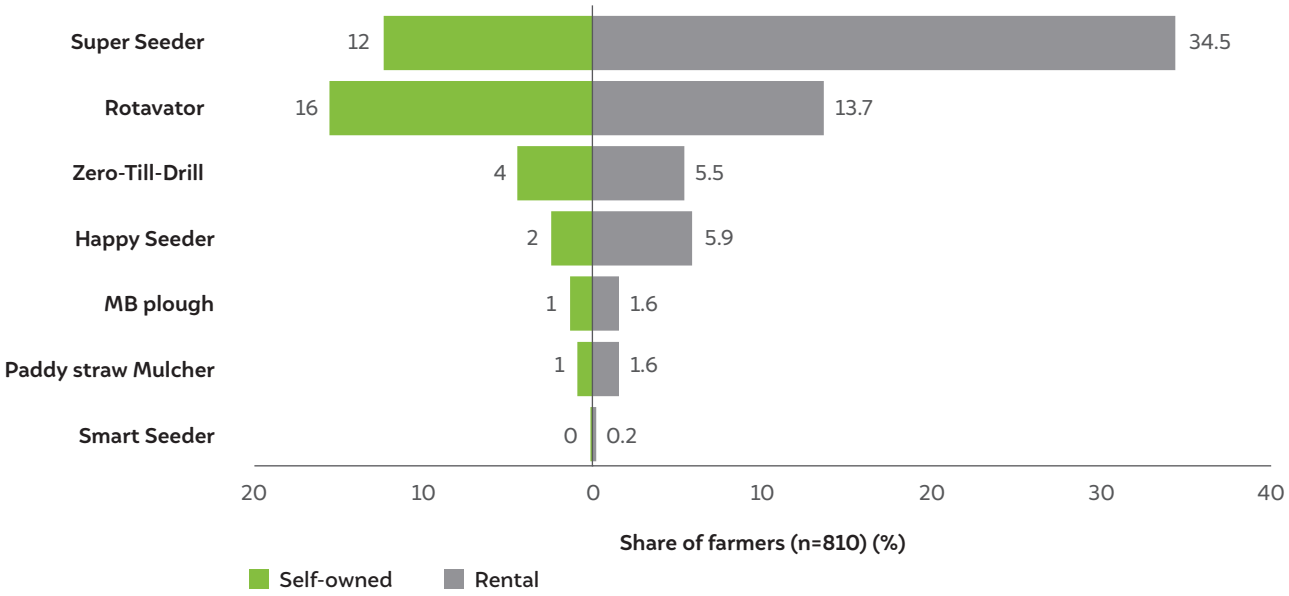
Note: The percentage of farmers adopting different CRM practices does not add up to 100 per cent since farmers tend to adopt more than one type of CRM method.

Personal connections are valued over digital solutions while renting CRM machines

- Over 63 per cent of in-situ CRM machine users rented them, a practice particularly prevalent among small and marginal farmers. Farmers who rented CRM machines primarily rented them from fellow farmers (82 per cent of rental CRM users) who were friends or relatives. Even those who accessed them through cooperative societies (12 per cent) or other sources such as custom hiring centres (CHCs) (3 per cent) relied on personal connections to obtain the machinery.

- Just 1 per cent of farmers use the Punjab Remote Sensing Centre's i-Khet app to access rental services for farm machinery. This is attributable to the fact that the current version of the i-Khet app collects extensive personal data, including Aadhaar numbers and land ownership information, resulting in limited acceptance among farmers.

Figure ES2 Punjab primarily used the Super Seeder and Rotavator to manage paddy stubble in 2022



Source: Authors' analysis

Misconceptions about pest attacks and wheat yields continue

Nearly 77 per cent of farmers following in-situ methods reported maintaining traditional sowing practices without making the recommended changes. Among them, over 20 per cent who experienced a decline in wheat yield and pest attacks attributed these issues to the use of in-situ CRM machines. Incorporating the prescribed changes in the application of irrigation, fertilisers, and rodent control measures while using in-situ machines can mitigate concerns surrounding the decline in wheat productivity and pest attacks. Further, only 7 per cent of farmers practising in-situ methods had received any training in using CRM machines.

Ex-situ CRM is gaining momentum

- The adoption of ex-situ CRM, such as using stubble for fodder or energy production, is gaining popularity due to its potential for additional income. According to our survey, nearly 33 per cent of the surveyed farmers opted for ex-situ methods, and 66 per cent of these farmers had formerly employed in-situ methods to manage their stubble. This indicates a clear preference for ex-situ over in-situ options, as costs associated with in-situ methods continue to be a burden for farmers.
- Ex-situ methods include providing residue to biomass aggregators/balers (60.4 per cent of ex-situ users), followed by supplying it to pastoral communities for fodder (28.8 per cent) and nearby industries.
- However, farmers adopting ex-situ methods are not entirely satisfied. A meagre 3 per cent of ex-situ farmers received payments of about INR 1,200 per acre when selling the paddy stubble. Moreover, while nearly 28 per cent had to pay the buyer to clear the stubble, 69 per cent gave the stubble away free of cost.

B. Strategies to improve the sustained adoption of CRM methods

In view of our findings, we recommend that all policy actors in Punjab and beyond focus on the following measures to reduce crop residue burning in the coming seasons.

Only 7% of farmers practising in-situ methods had received training in using CRM machines.

Paddy varietal diversification

- **Despite the ban on the cultivation of PUSA 44 by the Punjab government in October 2023, its seeds are still in circulation through private seed dealers.** The state must enforce strict inspections of private seed dealers, distributors and producers to ensure a complete phase out of the variety.
- The last two sowing seasons (2022 and 2023) involved a rapid depletion of seed stock for popular varieties such as PR 126 and PR 128. Many farmers had to resort to less popular varieties such as PR 121. Therefore, state authorities must encourage recognised institutions such as the Indian Council of Agricultural Research (ICAR), agricultural universities, government seed farms, the National Seed Corporation and state seed agencies to **undertake large-scale seed breeding and retention of popular PR varieties to meet the state's seed demand**.
- The initiative to procure summer *moong* at the minimum support price (MSP) if the farmers sowed PR 126 or basmati in the same field after harvesting *moong* in 2022 triggered massive demand for PR 126 seeds among farmers (Kamal 2022; Dey 2022). **The state must continue such incentives to promote the adoption of short-duration varieties among PUSA-growing farmers**.

In-situ CRM methods

- The state has been introducing new CRM machines annually under its CRM subsidy scheme – Super Seeders in 2020, Smart Seeders in 2022, and Surface Seeders in 2023. While Super Seeders are commonly preferred, machines such as Happy Seeders, Smart Seeders, and Super SMS have limited acceptance among farmers. To avoid incorrect resource allocation, it is imperative to assess the efficacy of these machines and farmers' preferences in terms of cost and yield through pilot programmes before incorporating them into the subsidy scheme. To this end, **the state must codify an evaluation framework to include only machines with demonstrated success in the CRM subsidy scheme**.
- The Punjab government has ambitious targets to scale the rental model of CRM machines through its i-Khet app. But the app in its current version collects extensive personal data, including Aadhaar numbers and land ownership information, making it less attractive among farmers. To resolve this, **the Punjab Remote Sensing Centre (PRSC) must upgrade the app to incorporate responsive design and cater to farmers' needs, preferences, and behaviours**. Further, it must enable the automatic alert feature to send personalised notifications covering the health and cost benefits of CRM methods, improvement in soil health, and savings made on agricultural inputs.

- Despite years of promotion and awareness drives, the survey highlights the prevalence of misapprehensions among farmers regarding pest attacks and productivity of wheat sown using CRM machines. This indicates a knowledge gap in integrating adequate changes to the cultivation practices that can mitigate these challenges. Therefore, the **Department of Agriculture and Farmers Welfare (in collaboration with technical institutes such as the Punjab Agricultural University (PAU)) must create a practitioner's guide, which lists the standard operating procedures and best practices while using CRM methods**.

- Training workshops by KVKs and agricultural departments are mostly scheduled towards the tail-end of the Kharif season (September) when the farmers are busy with harvesting and selling produce in local *mandis*. Instead, the **state must organise year-round training workshops** with well-curated content to cover not just zero-burn CRM methods but also the related changes needed in the cultivation practices of Rabi crops.

Only 2.9% of farmers following ex-situ CRM methods received payments while selling their stubble.

Ex-situ CRM methods

- While the ex-situ CRM sector is slowly growing in Punjab, our survey indicates that only 2.9 per cent of farmers following ex-situ methods received payments of about INR 1,200 per acre while selling their stubble. The remaining farmers either gave the stubble free of cost or paid around INR 1,000 per acre to clear the stubble. As per the latest CRM guidelines released by the Ministry of Agriculture & Farmers Welfare (MoAFW) in July 2023, the cost of collected biomass is to be mutually agreed upon by the farmer group/aggregator and industry based on the market condition. Therefore, **the Punjab Energy Development Agency (PEDA) must set a price floor for raw biomass and biomass-based products to ensure a minimum viable price for farmers to incentivise them not to undertake stubble burning**.

1. Introduction

CEEW team in conversation with a progressive farmer from Ludhiana who uses his rotavator to manage the standing stubble.

Following its Independence, India's push towards self-reliance in food grain ushered in the Green Revolution (John and Babu 2021). The Green Revolution saw a massive investment in crop research, mechanisation, infrastructure, market development, and appropriate policy support. The policy thrust on the self-sufficiency of food grains led north-western Indian states such as Punjab to specialise in the cultivation of wheat and paddy (Dutta 2012). The inherent water-intensive nature of paddy and the resultant decline in groundwater availability compelled the Punjab government to enact laws altering the natural crop cycle of paddy (Gupta 2019). This policy action inadvertently led to the synchronisation of the Rabi and Kharif crop cycles, encouraging the practice of crop residue burning (Gupta 2019; Kurinji and Prakash 2021).[4]

4. We use crop residue burning, stubble burning, and agricultural residue burning synonymously.

1.1 Policy efforts to curb crop residue burning in Punjab

The high incidence of farm fires and resultant air pollution in the Indo-Gangetic plains have spurred policy action at the central and state levels. In 2018, the union government launched its flagship scheme, *Promotion of Agricultural Mechanisation for In-situ Management of Crop Residue in the States of Punjab, Haryana, Uttar Pradesh, and the NCT of Delhi*. The scheme subsidised the cost of owning and renting in-situ crop residue management (CRM) equipment, such as the Happy Seeder and Super Seeder, encouraging their adoption across the three states (MoAFW 2020). Under this scheme, Punjab received over INR 1,387.6 crore during 2018–22 to address stubble burning (PIB 2022).

In addition, the Government of Punjab introduced financial incentives to farmers using sustainable CRM solutions and one-time incentives for ex-situ end-users (Kurinji and Prakash 2021). Yet, despite the existence of solutions and policy support, farm fires remain a persistent policy conundrum (Figure 1).

Figure 1 Farm fires have been on the decline since 2021

Source: Authors' analysis; active fires and thermal anomalies product from NASA VIIRS 375 m

Note: Only open fires with high and nominal confidence values were considered.

As per the Punjab government's action plan submitted to the union government in 2022, the state aims to manage over 20.5 million metric tonnes (MMT)[5] of paddy straw through in-situ and ex-situ CRM and crop diversification by the financial year 2023–24 (Government of Punjab 2022a) (Table 1). In early 2023, the Punjab chief secretary assured the Commission for Air Quality Management (CAQM) that the state would reduce 50 per cent of farm fire cases in 2023 compared to the previous year (Express News Service 2023a). To ensure a smooth transition to the zero-burn CRM methods, it is essential to learn from the experiences, challenges, and good practices followed in various districts.

5. Punjab generates 16–20 Mt of paddy straw every Kharif season. The quantum of residue generated is proportional to the area sown with paddy.

Table 1 Punjab expects to manage the total surplus paddy stubble generated annually by 2023–24

No.	Strategy	Paddy residue utilisation target (Mt)			
		2020–21	2021–22	2022–23	2023–24
1.	Crop diversification	2.57	3.57	4.57	5.22
2.	In-situ CRM	6.45	8.13	9.44	10.70
3.	Ex-situ CRM	0.92	1.22	1.52	4.67
	Total	**9.94**	**12.92**	**15.53**	**20.59**

Source: Government of Punjab (2022a); Government of Punjab (2022b)

Interactions with farmers across various regions highlight multiple issues, including the absence of timely access to CRM machines, inflated operational charges of CRM machines, the lack of biomass end-users to collect the crop residue on time and misapprehensions regarding yields and pest attacks on wheat sown using in-situ CRM machines (Kurinji and Prakash 2021; Prakash and Singh 2022). Notwithstanding these claims, evidence of farmers' experiences adopting zero-burn CRM methods is limited. Publicly available data is limited to supply-side metrics, such as the number of CRM machines disbursed at the state/district level, the number of custom hiring centres (CHCs) established and funds distributed (Government of Punjab 2022a). As per the latest government data, Punjab has over 1.17 lakh CRM machines and 24,201 CHCs (PIB 2023). While these statistics are encouraging, they are insufficient to determine the sustained adoption of CRM methods by farmers.

We aim to address this data gap by conducting a primary survey to evaluate the accessibility, affordability, and utilisation of CRM solutions by farmers. This survey provides a multidimensional evaluation of the state of CRM in Punjab, highlighting multiple nuances associated with the sustained adoption of CRM methods. Through this study, we aim to inform the union and Punjab governments of the challenges farmers face on the ground, and recommend policy measures to overcome them.

CEEW team in conversation with a cattleman regarding the growing interest of using paddy straw for fodder in northern districts such as Amritsar, Gurdaspur and Jalandhar and in certain pockets of Rajasthan.

1.2 Study objectives

In this study, we reflect on the current state of CRM in Punjab, the progress made over the last five years, and the persisting gaps and emerging trends. The research objectives are listed in Table 2.

Table 2 Selection of research objectives

Policy measures to address stubble burning	Gaps identified	Research question
• Promotion of short-duration paddy varieties (2010s)	• Continued preference for long-duration variety due to high yields	• How can Punjab achieve paddy varietal diversification?
• Subsidies for CRM machines such as the Happy Seeder and Super Seeder (2018 onwards) • Establishment of CHCs to improve access to CRM machines (2018)	• Limited adoption of CRM machines • Limited uptake of rental models to access CRM machines	• Have the recent government schemes influenced the adoption of pollution-free CRM methods in Punjab? • To what extent has the increase in CRM machines resulted in reduced open burning of farm waste, and what factors can explain the continued gaps?
• Co-firing biomass pellets in thermal power plants (2017) • Financial assistance to set up agro residue–based bio-CNG plants (2018) • Financial incentives to industries to consume biomass as a boiler fuel (2021) • Financial incentives to set up biomass collection depots (2023 CRM guidelines)	• Not enough evidence in terms of farmers' preference for ex-situ methods • Limited biomass end-users	• Can ex-situ CRM methods gain traction among Punjab's farmers?

Source: Authors' compilation; Kurinji and Prakash (2021)

We have structured this report as follows. Section 2 describes the study design and methodology. Section 3 highlights the changing contours of cropping preferences. Section 4 delves into how farmers manage crop residue across districts. In Sections 5 and 6, we discuss whether farmers are satisfied with in-situ CRM methods and whether the methods need recalibration. Section 7 discusses what role ex-situ CRM methods can play in Punjab. In Section 8, we synthesise the key findings and provide policy recommendations for policymakers and various state-level actors.

2. Survey design

We provided a thorough training to all the 12 survey enumerators involving classroom discussions of the questionnaire, role-play exercises, and mock surveys in the field in Feb 2022.

To assess the status of the adoption of zero-burn CRM practices in Punjab, we conducted an independent survey with 1,478 farmers from 11 districts of Punjab between March and May 2023. We chose a sampling size of 1,478 farmers to mirror Punjab's farmer population as per the latest agricultural census (2015).[6] The selected districts – Amritsar, Bathinda, Fatehgarh Sahib, Fazilka, Firozpur, Gurdaspur, Jalandhar, Ludhiana, Patiala, Sangrur, and SBS Nagar – collectively accounted for about 58 per cent of the Kharif farm fires reported in Punjab in 2022. We hired a survey agency to administer the survey in Punjabi and Hindi.

6. As per the standard rule, we considered the margin of error as 3 and the confidence interval as 95 per cent while deciding the sample size.

2.1 Multi-stage stratified sampling strategy

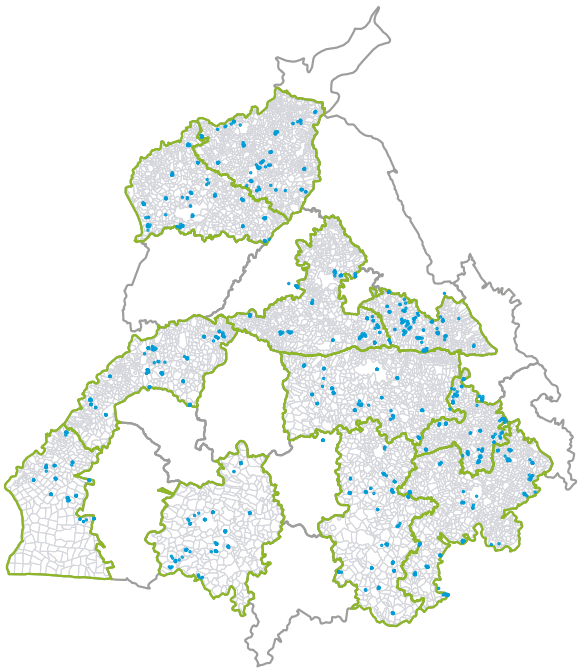
We used a random sampling approach with multiple levels of stratification (Figure 2). First, we categorised 22 districts of Punjab into 3 classes – high-burn, medium-burn, and low-burn districts. We chose the number of fire counts per unit area (1,000 acres) under non-basmati cultivation to categorise the districts (refer to Annexure A1). Districts with a fire count intensity in the first tertile (< 33.3 percentile value) were considered low-burn, districts in the middle tertile were considered medium-burn, and districts in the highest tertile (> 66.6 percentile) were considered high-burn. Given the logistical and resource constraints, we randomly sampled 3–4 districts in each category for a total of 11 districts across Punjab.

For the second level of stratification, using 2011 census data, we first categorised villages in each sampled district into two groups – small and large – based on their population size. From each village, we then sampled three small and marginal farmers, six semi-medium and medium farmers, and one large farmer to mirror Punjab's farmer population across different landholding categories. This formed our third level of stratification. Considering there is no comprehensive list at the farmer level, we adopted a convenience-based sampling approach to meet the target set on the number of farmers across different landholding categories in each village. Figure 3 describes the characteristics of the sample selected for this study.

Image: Srishti Jain/CEEW

CEEW's Harsha Arya interacting with the secretary of a Custom Hiring Centre to understand the challenged faced them.

Figure 2 We employed a multi-stage stratified sampling approach, covering 1,478 farmers from 11 districts in Punjab



11 Districts

Stratified based on farm fire density

143 main villages

(5–10 backup villages in each district) *

Probability proportional to size (PPS) sampling

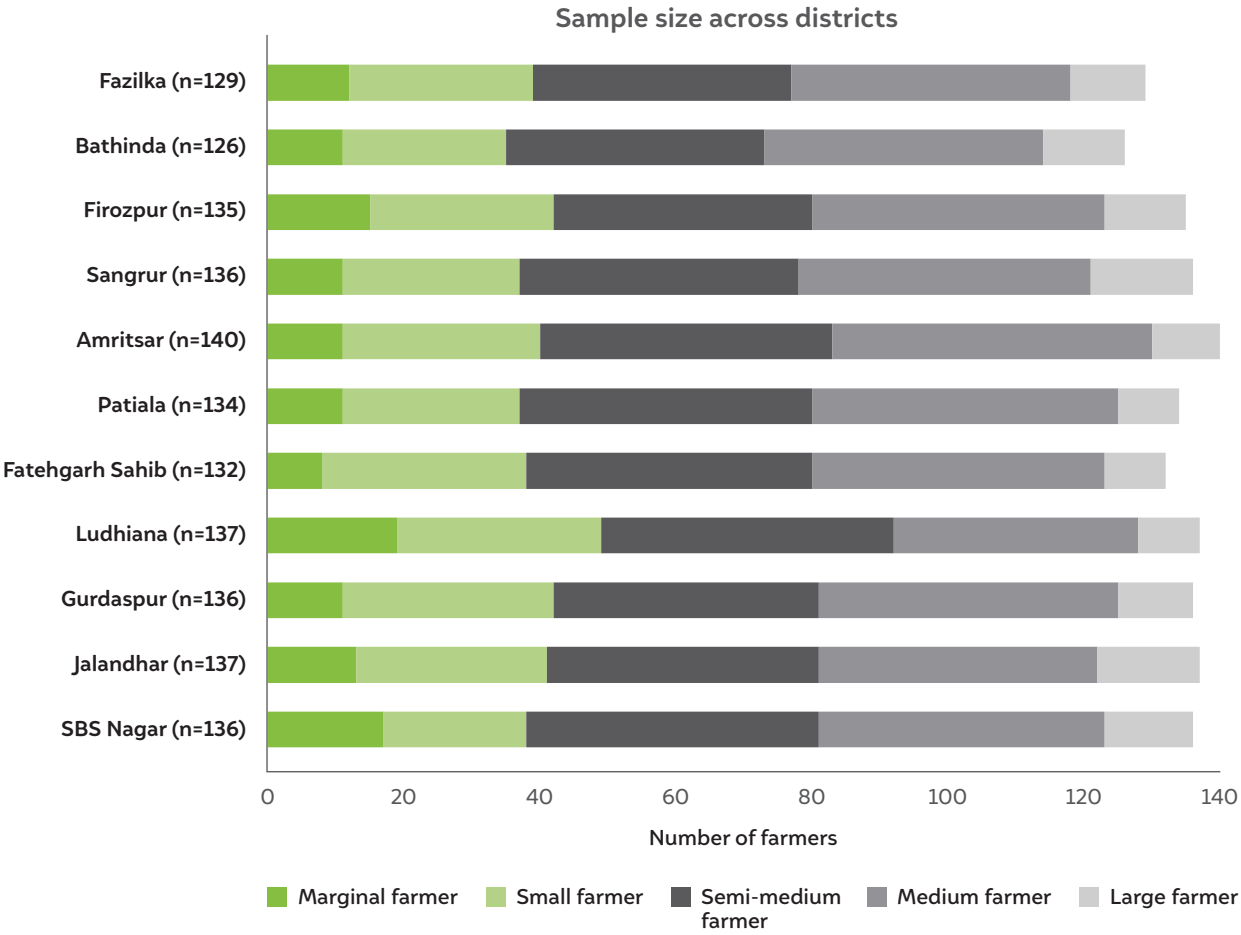
1,478 farmers

(~10 farmers in each village)

Sampling through random walk

Three small and marginal farmers, six semi-medium and medium farmers, and one large farmer*

PPS sampling



Source: Authors' analysis

Note: We resorted to a list of backup villages in each district as the said number of farmers based on landholding categories, particularly in the case of large farmer groups, was difficult to meet in some villages. This is mainly because renting out land to other farmers (tenants) is common among farmers in the large landholding category in Punjab.

Figure 3 Sample characteristics

Social groups	84%	11%				5%
	General	Other Backward Class (OBC)				Scheduled Caste/ Scheduled Tribe
Groups associated	55%	23%	16%	6%		25%
	Self-help group/ cooperatives	Farm unions	Panchayat members	Registered farmer groups		Not associated with any group
	~4% responded 'Others' and some farmers are associated with more than one group					
Sources of income other than agriculture	70%	13%	5%	4.7%	4.6%	2%
	Cattle rearing	Own business	Remittances	Salaried job	Pension	Casual agriculture labour/daily-wage labour
	~17% responded 'No other source of income other than agriculture'					
Education	11%	9%	45%	23%		13%
	Uneducated	Primary school (Class 5)	High school (Class 6–10)	Senior secondary school (Class 11–12)		Undergraduate & above

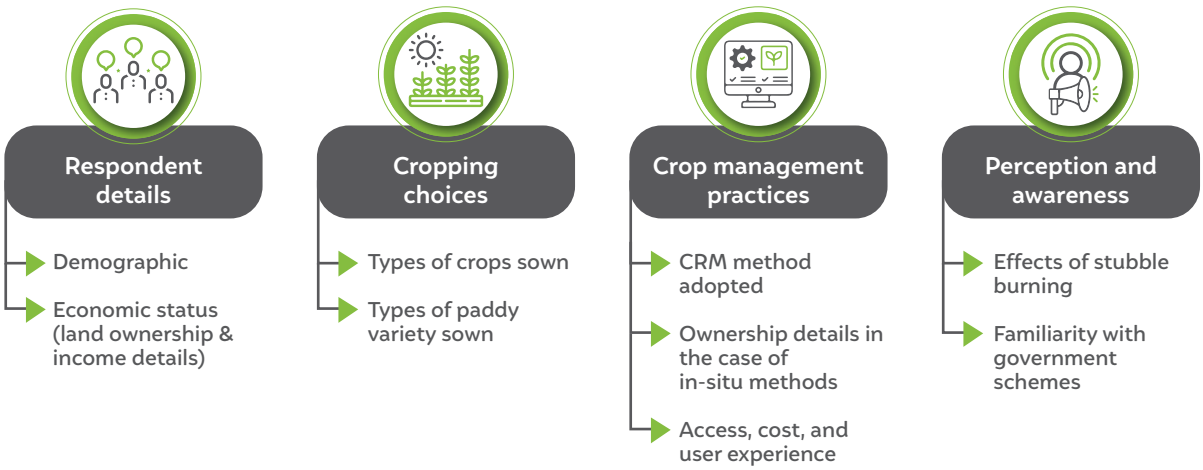
Source: Authors' analysis

2.2 Questionnaire design

We designed a structured questionnaire to capture farmers' behaviour on crop choices and CRM practices. The survey instrument included questions about farmers' preferences for different paddy seed varieties, the type of CRM method followed, experiences with the adoption of no-burn CRM methods, awareness of the effects of stubble burning and overall outlook, benefits, and challenges associated with the adoption of different CRM methods (Figure 4). The median time per interview was 20 minutes.

We developed the first draft of the questionnaire after reviewing the existing literature on crop residue burning and field interactions with farmers, Krishi Vigyan Kendras (KVKs), and agricultural officers. We revised the questionnaire after receiving inputs from experts within CEEW. Following that, we translated the questionnaire into Punjabi and piloted it in non-sampled villages in four districts – Ludhiana, Sangrur (Malerkotla), Patiala, and Rupnagar. The final questionnaire incorporated inputs from the pilot surveys.

Figure 4 Framework of the crop residue management survey questionnaire



Source: Authors' analysis

2.3 Qualitative interviews with farmers and agricultural officers

We conducted field visits in the Malwa region in October and November 2022, interviewing officials from agricultural departments and farmers to understand the current state of CRM practices. These interactions played a crucial role in shaping the design of our survey questionnaire. Following the completion of our primary survey, we interviewed KVK and agricultural department staff from three districts – Patiala, Fatehgarh Sahib, and Ludhiana – during the analysis phase in June 2023 to validate key findings of the survey.

2.4 Data quality and limitations

Survey responses are generally susceptible to numerous errors such as recall bias, enumerator bias or measurement errors. To mitigate these issues and ensure data quality, we employed multiple strategies, such as building adequate checks, skips and value limits (upper and lower bounds) into the data collection software to reduce incorrect, missing, or invalid responses. The enumerators underwent thorough training to accurately code the diverse responses.

Throughout the data collection phase, we performed sanity checks on small data batches to identify gaps. We reported cases of incorrect responses to the survey agency for cross-verification or re-survey. Observations were dropped if the quality of the data was doubtful. We also visited multiple survey sites to observe the enumerators at work. This aided us in prescribing timely, corrective measures for the interview process and better understanding the context of the responses.

Despite these efforts, we cannot entirely overlook the possibility of errors in the survey data, such as the following:

- Questions on the expenditure incurred for buying or renting CRM machines are vulnerable to recall bias.
- The survey was administered in Punjabi. While we attempted to minimise translation and interpretation errors through pilot surveys, given the use of local terms and dialects for various farming processes, some questions may not have been administered adequately for a few farmers.
- In some cases, we observed that farmers were not honest about burning farm waste in the field. While we included adequate check questions to cross-verify the responses, there are possibilities for inaccurate responses in this variable. Therefore, we recommend prudence while using such data insights.

Nearly 66% of surveyed farmers preferred short duration paddy variety in Kharif 2022 that offers longer window for stubble management.

Image: Kurinji Kemanth/CEEW

3. How did cropping preferences change?

The choice of paddy variety sown has a direct connection with stubble burning cases in Punjab. In this section, we break down the variables, such as the area sown with different paddy varieties, the preferred paddy varieties among farmers and the reasons driving their choices.

Over 66% of surveyed farmers cultivated short duration paddy varieties in Kharif 2022.

3.1 Leveraging the rising popularity of short-duration varieties to promote their uptake among reluctant farmers

Historically, high-yielding long-duration varieties such as PUSA 44 and Peeli PUSA have dominated the paddy fields in Punjab. These varieties are infamous for their long crop duration, excess straw generation, and high agricultural input (fertiliser, pesticides, and water) consumption (J. M. Singh et al. 2022). For instance, PUSA 44 generates almost 2 tonnes of excess straw per hectare compared to its PR (Parmal rice) variants, leading to more residue burning (Table 3). Since the early 2010s, the government has been promoting nine short-duration varieties to fight the dual problem of groundwater depletion and stubble burning (Punjab Agricultural University 2014). The encouraging trend is that the acreage of short-duration varieties has seen a drastic rise in Punjab over the last decade – from 32.6 per cent in 2012 to 69.8 per cent in 2021 (Dhillon and Gill 2022).

During our survey, over 66 per cent of the surveyed farmers confirmed cultivating short-duration PR varieties in 2022. Among these short-duration varieties, PR 126 emerged as the most sought-after variety despite its limited supply. Of the PR growers, 57.7 per cent sowed PR 126 in Kharif 2022. In the previous year, the Punjab Agricultural University produced over 2,600 quintals[7] of PR 126 seeds, making them available for sale on 30 March 2022. Ground reports indicate that the entire seed stock was emptied in under a month (Khanna 2022). One of the reasons for the demand surge could be the Punjab government's announcement in May 2022 to procure summer *moong* dal at the minimum support price (MSP), provided the farmer sows PR 126 or basmati in the same field after harvesting *moong* (Kamal 2022; Dey 2022). Farmers primarily opted for this newly promoted variety in view of the assured procurement of summer *moong* by the government.

7. 1 quintal = 100 kg.

When queried about seed preferences for the Kharif 2023 season, nearly three-fourths of PR 126 growers expressed willingness to continue with the variety, citing its superior performance in the previous season. This demand surge resulted in a seed supply shortage in the 2023 paddy sowing season. Overcoming this necessitates the large-scale production of high-quality seeds by Punjab Agricultural University and other seed breeding agencies. In addition, state actors must encourage farmers to retain quality seeds for continued sowing in the seasons to come.

Table 3 Short-duration varieties outperform PUSA 44 on environmental benefits

Parameters	PUSA 44	PR 121	PR 126
Year of release	1993	2013	2017
Average yield (quintals per acre)	32	30.5	30
Crop maturity in days (after transplantation)	130	110	93
Interval between paddy harvest and wheat sowing (in days)	7–10	22–27	25–40
Average plant height (cm)	105	98	102
Straw yield (tonnes per hectare)	10.9	8.2	8.2
Time of nursery sowing		May 20–25	May 25–June 20
Recommended transplanting time	June 20–30	June 20–25	June 25–July 5
Number of irrigations per cropping cycle	31	26	23

Source: Authors' compilation from the PAU package of practices (Punjab Agricultural University 2023; Dhillon and Gill 2022; National Green Tribunal 2019)

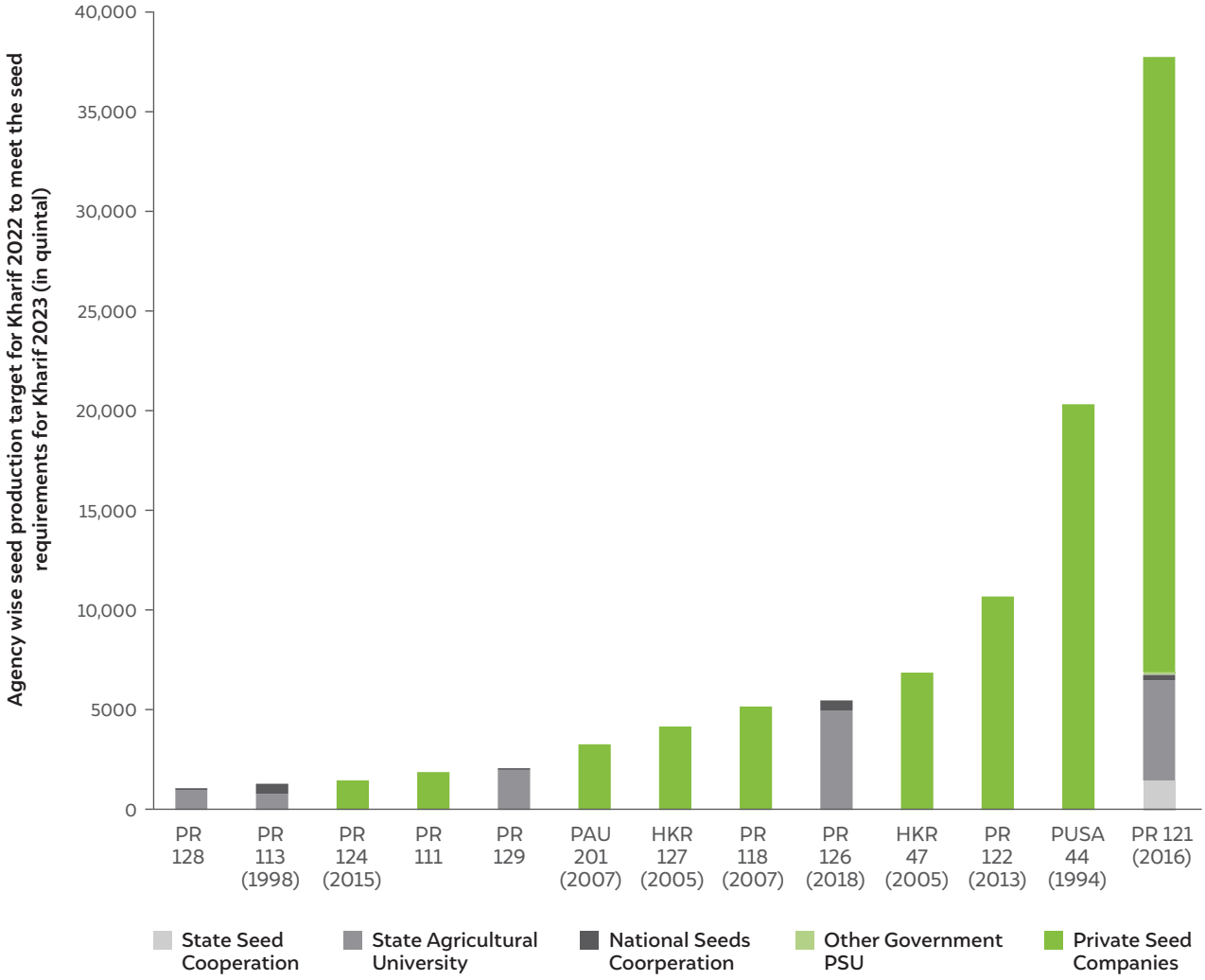
3.2 Variety inertia continues in the era of newer, improved paddy varieties

Acknowledging the environmentally detrimental traits of PUSA varieties (see Table 3), in 2017, the PAU included PUSA 44, Peeli PUSA, and Dogar PUSA on the list of unrecommended varieties, urging the state to discontinue such decades-old varieties (Mishra 2021; Goyal 2017). While interviewing for this study, over 36 per cent of the surveyed farmers confirmed cultivating PUSA 44 in 2022. Despite the Indian Agricultural Research Institute having discontinued breeder seed production of PUSA 44 in 2017, state actors anticipate that the seeds stocked by farmers will likely be exhausted in the coming seasons, leading to the phase-out of the variety only by 2025 (Joshi 2022). However, just 37 per cent of PUSA growers utilised stocked seeds from the previous season. On the contrary, PUSA 44 seeds were primarily sourced from private dealers; over 67 per cent of PUSA growers indicated that their seeds were purchased from private dealers.

Our interactions with private seed dealers revealed that while the production of breeder and certified PUSA 44 seeds had ceased, truthfully labelled PUSA 44 seeds were still in circulation. This category represented a notified seed variety produced by cultivators and private seed companies, falling outside the purview of the Department of Seed Certification (Tamil Nadu Agricultural University n.d.). In this case, the farmer and user lacked information about the pedigree of the truthfully labelled seed and relied on the seed-producing company for its quality (Mehandi n.d.).

Further, we reviewed Punjab's seed rolling plan submitted in 2020 to assess if the state's procurement plan aligns with the varietal preferences among farmers. State governments typically prepare the seed rolling plan three years in advance to compute the seed requirements in their state and distribute seed production targets accordingly to different seed production agencies (MoAFW 2022a). This system ensures the timely availability of quality and certified seeds to all farmers. As per the seed rolling plan of 2020, PUSA 44 accounted for almost 20 per cent of the production and distribution target set for non-basmati paddy seeds in 2022 to meet the seed requirement during Kharif 2023 (Figure 5), with the entire 20 per cent share allocated to private seed companies (MoAFW n.d.). In October 2023, the state officially banned the cultivation and sale of PUSA 44 variety. However limited seed stock of PR varieties and easy access to PUSA 44 seeds through private seed dealers prevent farmers from discontinuing the banned variety.

Figure 5 PUSA 44 accounted for 20% of the seed production target in 2022

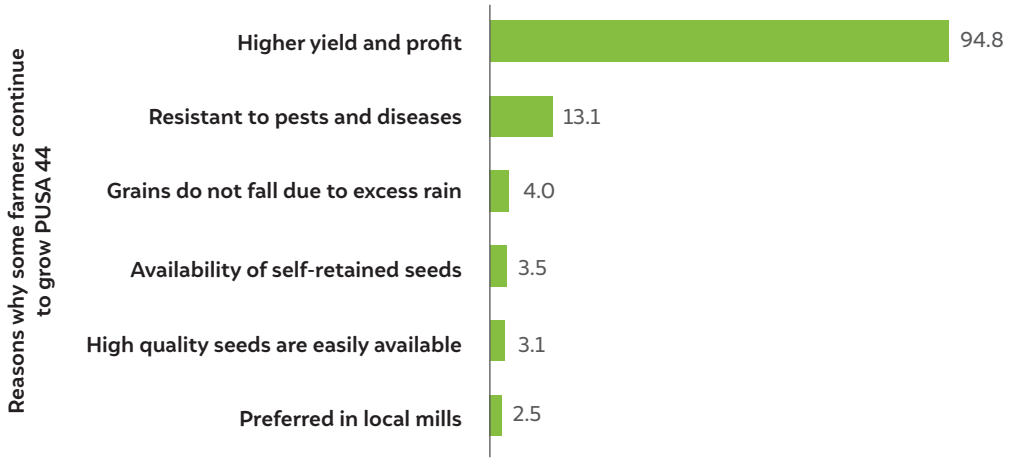


Source: Authors' compilation; data retrieved from Punjab's Seed Rolling Plan 2020

Note: The year of release for non-basmati paddy varieties is indicated in brackets along the x-axis.

When farmers were queried about the factors influencing their purchase decision when buying PUSA 44 paddy seeds, 'higher yield' emerged as the most frequently stated criterion, followed by 'resistance to pests' (Figure 6). This preference may be because farmers perceive only the relatively higher yield of PUSA 44 and lack an understanding of its implications on fertiliser, pesticide, and water use. Research reports from Punjab Agricultural University indicate that farmers could achieve a net profit of INR 193 and INR 106 per acre through savings in fertiliser and pesticide use through a varietal shift to PR 121 and PR 126, respectively (Joshi et al. 2018; Dhillon and Gill 2022). Further, long-duration variants consume 16 per cent more water and 30 per cent more energy compared to PR varieties such as PR 121 (Joshi et al. 2018). Currently, subsidised electricity for agricultural irrigation obscures the savings made on energy and water.

Figure 6 Farmers cite higher yield as the reason for growing PUSA 44



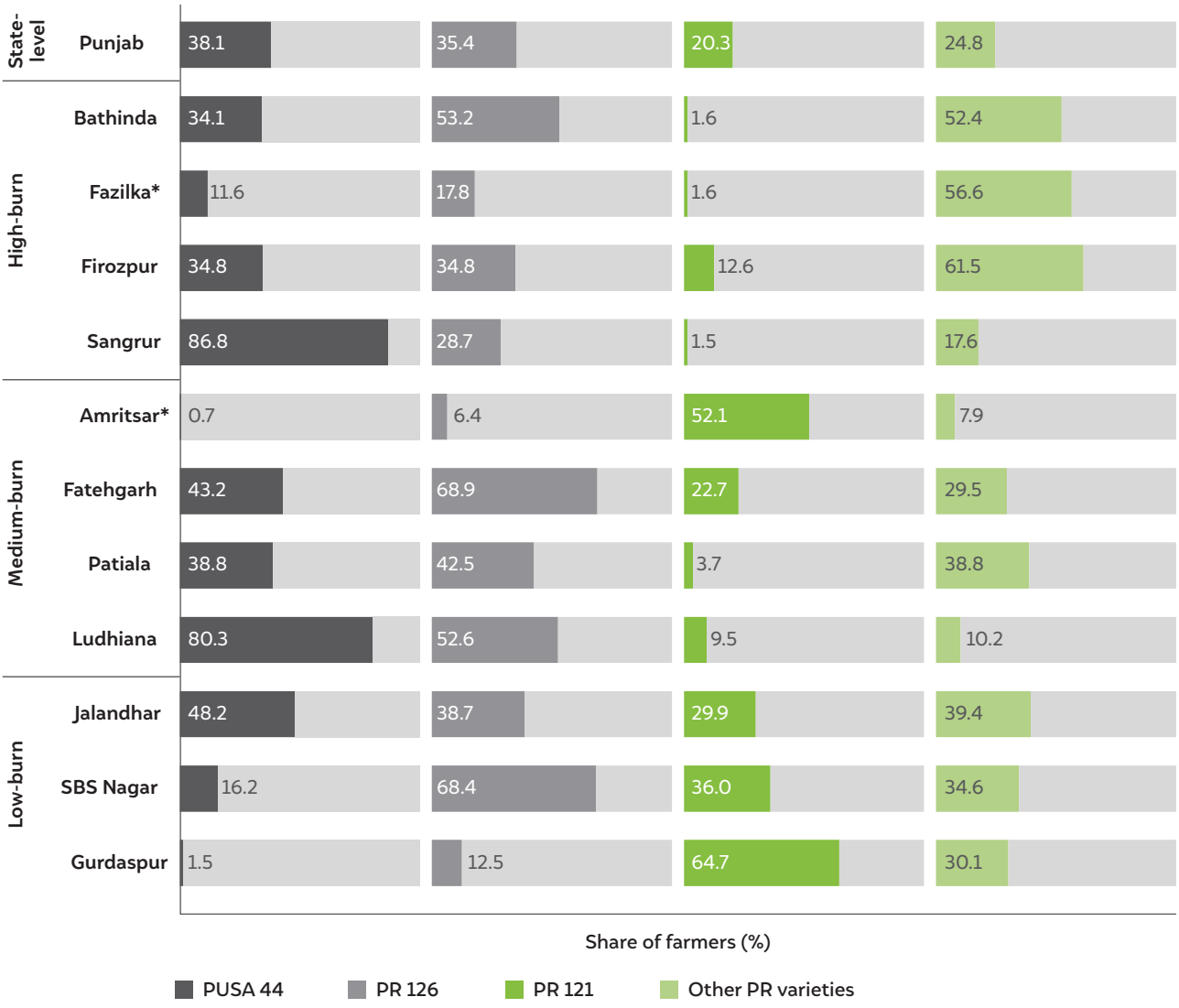
Source: Authors' analysis

Some farmers practise partial burning to clear the loose straw after harvest in order to ensure smooth operation of CRM machines.

3.3 Variations in seed preferences across Punjab districts

Figure 7 displays the status of short- and long-duration paddy growers at the district level. While the newly promoted PR 126 variety holds the ground in southern districts, other popular varieties, such as PR 121, continue to be widely grown in the Majha region (western border districts of Amritsar and Gurdaspur). High- and medium-burn districts such as Sangrur and Ludhiana have the highest proportion of PUSA growers in combination with PR varieties. Western border districts such as Amritsar, Fazilka and Gurdaspur have limited non-basmati PUSA growers since the region primarily grows basmati.

Figure 7 The southern and central districts of Punjab have the maximum growers of PUSA 44



Source: Authors' analysis

Note: Most farmers grew more than one paddy seed variety; therefore, the sum of each row would be more than 100 per cent. In Amritsar and Fazilka, most farmers grew basmati. This is one of the reasons why fewer farmers grew common varieties such as PUSA 44, PR 126 and PR 121.

CEEW's Kurinji in conversation with Ashish Kumar, Verbio India on the steps followed while sourcing crop biomass from farmers for bioCNG production.

Image: CEEW

4. Do farmers burn or bury crop residue?

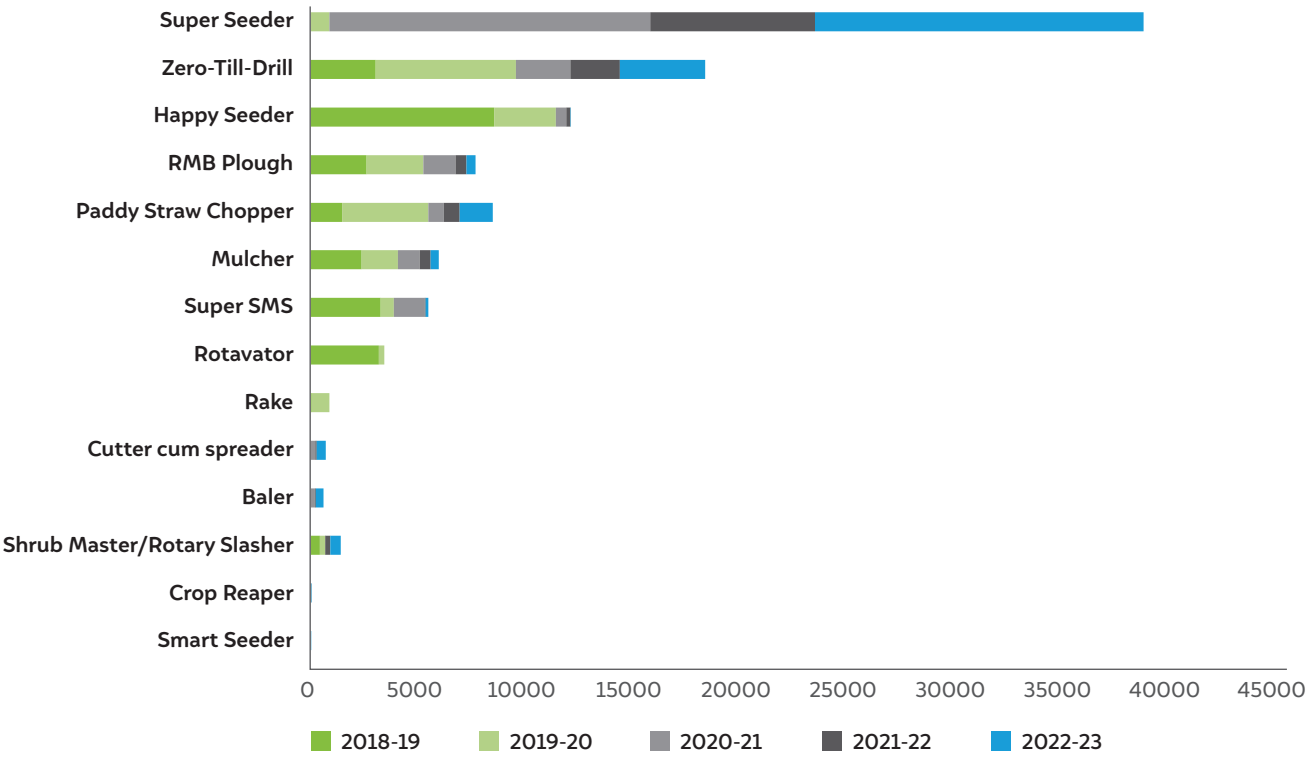
Crop stubble can be managed through in-situ and ex-situ methods. While the former deals with managing residue on the farm through incorporation, mulching, or decomposition, the latter treats them offsite for energy or fuel production (Singh et al. 2020). Providing accessibility to these zero-burn methods is the first step towards curbing stubble burning. However, the high costs associated with these methods compared to open burning act as a significant deterrent (Kurinji and Prakash 2021; Lopes, Viriyavipart, and Tasneem 2020). In this section, we delve deeper into the type of CRM methods preferred by farmers and the reasons for continued open burning of stubble in Punjab.

Super Seeders accounted for 38% of all machines sanctioned under the CRM scheme.

4.1 Nearly 1 lakh machines to manage stubble, yet burning persists in Punjab

To curb stubble burning, the union government launched the central-sector scheme on the *Promotion of Agricultural Mechanisation for In-situ Management of Crop Residue* in 2018–19 to subsidise machines such as the Super Seeder and Happy Seeder (MoAFW 2020). The scheme offered subsidies for over 14 different types of machines. Till 2022–23, Punjab had received over INR 1,387.6 crore and deployed over 1.1 lakh machines (MoAFW 2022b). Analysing the purchase trend of CRM machines over the years indicates that Punjab's farmers primarily preferred newer machines such as the Super Seeder, followed by the Zero-Till-Drill and Happy Seeder (Figure 8). Super Seeders accounted for 38 per cent of all machines sanctioned under the CRM scheme. One reason for the greater preference for the Super Seeder is that the tractor-mounted machine can cut the stubble, mix it with soil, prepare the land, and simultaneously sow seeds in a single pass. Since the stubble is buried in the soil, the field looks clear in the case of the Super Seeder. In contrast, the Happy Seeder employs the mulching technique, and the residue remains in the field for a longer duration, even after the wheat crop has grown.

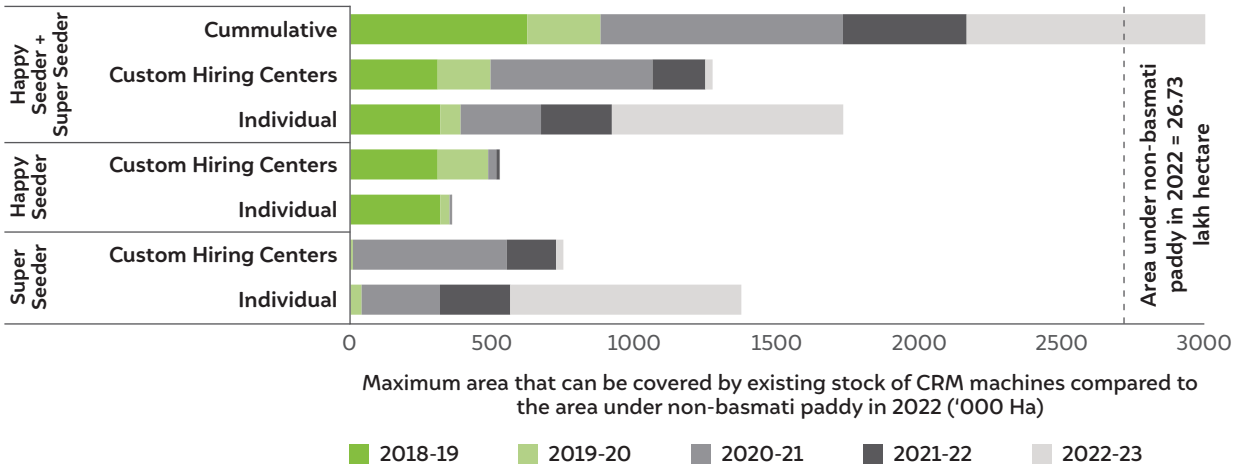
Figure 8 Super Seeders account for 38% of CRM machines sanctioned in Punjab



Source: CEEW compilation; data for 2018–22 was collated from an RTI reply dated 13 March 2023; data for FY2022–23 was compiled from DoAFW Punjab (n.d.)

The state has 43,452 Super Seeders and 13,560 Happy Seeders[8] – the two most promoted CRM machines. Nearly 59 per cent of them are owned by individual farmers, and the remaining are operated by CHCs. Collectively, these machines can cover 100 per cent of the non-basmati paddy fields in Punjab if deployed at maximum capacity (Figure 9). Annexure A2 provides the assumptions considered in estimating the total area that Happy Seeders and Super Seeders can manage.

Figure 9 The existing stock of Supers Seeders and Happy Seeders is sufficient to manage the total area under non-basmati paddy fields in Punjab

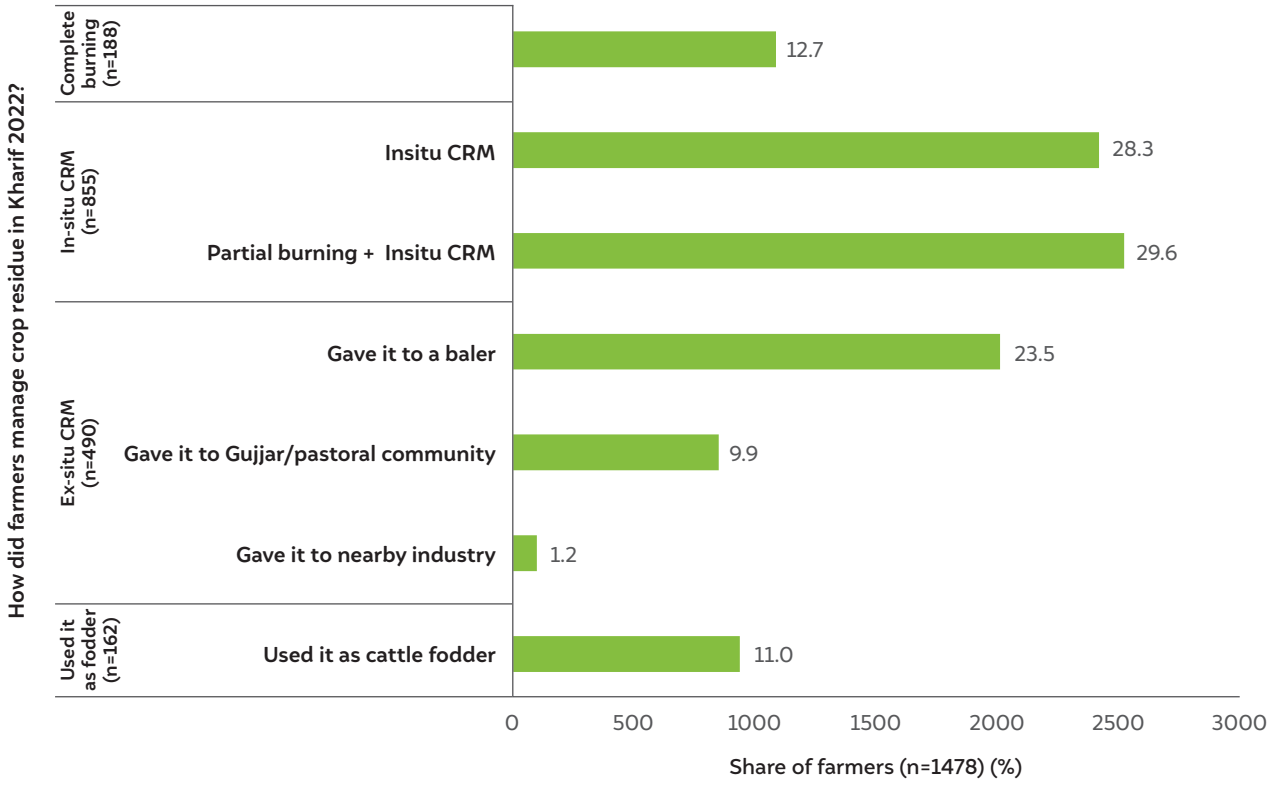


Source: Authors' analysis

8. Data corresponds to years between 2018 and 2022.

Despite the technology penetration, our survey indicates that nearly 13 per cent of Punjab's paddy farmers burned their paddy straw completely during Kharif 2022 (Figure 10). The practice of stubble burning was more pronounced among farmers in the Malwa region. Nearly 25 per cent of farmers in high-burn districts such as Sangrur, Bathinda, Firozpur and Fazilka practised complete burning. In contrast, in the case of medium-burn central districts such as Ludhiana and Fatehgarh Sahib, less than 10 per cent of farmers practised complete burning (Annexure A2).

Figure 10 Over 13% of Punjab's farmers burned their stubble completely in Kharif 2022

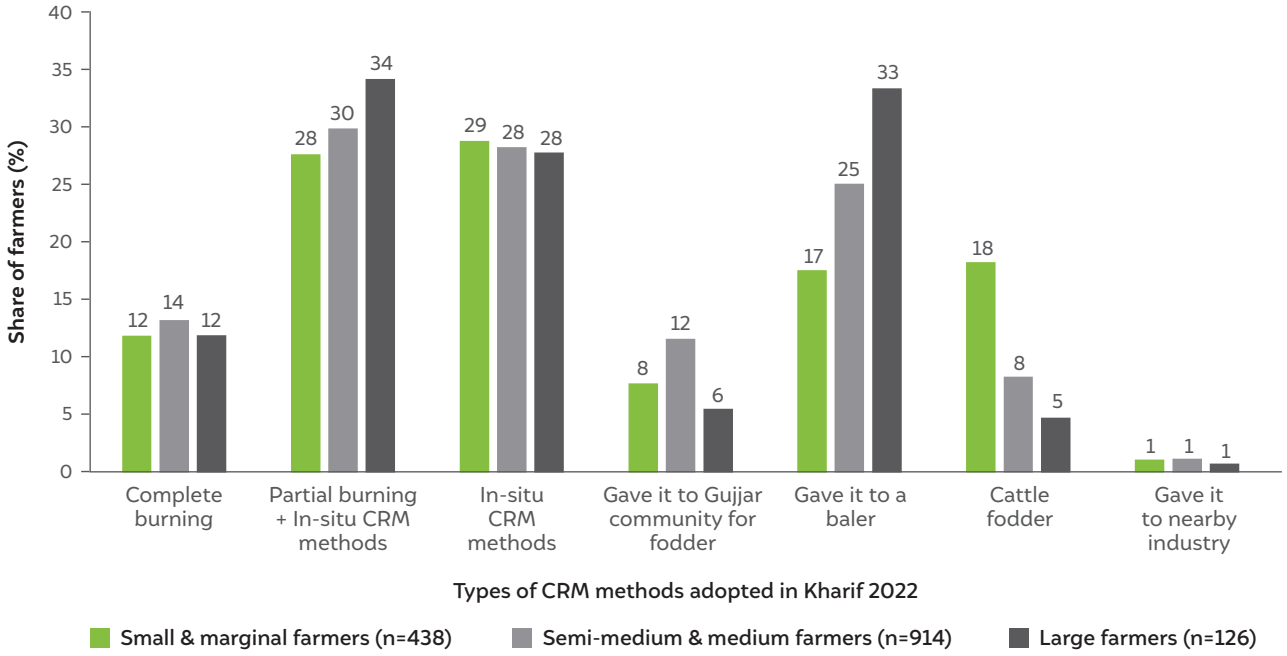


Source: Authors' analysis

Note: The percentage of farmers adopting different CRM practices does not add up to 100 per cent since the same farmer tends to adopt more than one type of CRM method.

In the past, several ground reports have documented that stubble burning is more prevalent among small and marginal farmers, given their limited ability to incur residue management costs (Rajpurohit 2022). Contrary to popular belief, our survey found that the trend of burning was more common among medium and large farmers than small and marginal farmers in 2022 (Figure 11) (Lopes 2020). Over 15 and 14 per cent of large and medium farmers practised complete burning in Kharif 2022, respectively. This number stands slightly lower, at 12 per cent, for small and marginal farmers. A similar trend was observed in the case of partial burning – 34 and 30 per cent of large and medium farmers adopted partial burning before using in-situ machines, respectively, compared to 28 per cent in the case of small farmers. Interactions with farmers during the analysis phase revealed that one of the reasons for the shift in trend could be the increased fear of receiving financial penalties and red entries in revenue records, which were made more stringent in the post-COVID years (Nibber 2022).

Figure 11 Crop residue burning is more popular among medium and large farmers compared to small and marginal farmers



Source: Authors' analysis

4.2 Partial burning is the new norm in Punjab

While it is encouraging to observe that nearly 58 per cent of the surveyed farmers adopted various in-situ technologies such as the Super Seeder and Rotavator for residue management, nearly half of them practised partial burning before using the machine in Kharif 2022 (see Figure 10). Using this method, farmers burn only a portion of the stubble instead of all of it. They do not use a cutter or the Super Straw Management System (SMS) to spread the residue evenly after using the combine harvester; instead, they create heaps and set the residual straw on fire (CII 2019). Burning in this method lasts only for a few hours, making it difficult for satellites to detect.

Nearly 88 per cent of the surveyed farmers who practised partial burning in 2022 said that they do so to ensure the smooth operation of CRM machines (Rajpurohit 2022). Over 20 per cent of the farmers believe that partial burning incurs relatively lower costs and controls pests. According to officials from the agricultural department, one way to rectify this is to use a Super SMS–attached combine harvester while harvesting paddy. This technology can cut and spread the straw coming out of the harvester evenly for a uniform straw load in the field (Hindustan Times 2020). The use of the Super SMS is considered a prerequisite for adopting CRM machines such as the Happy Seeder or Super Seeder.

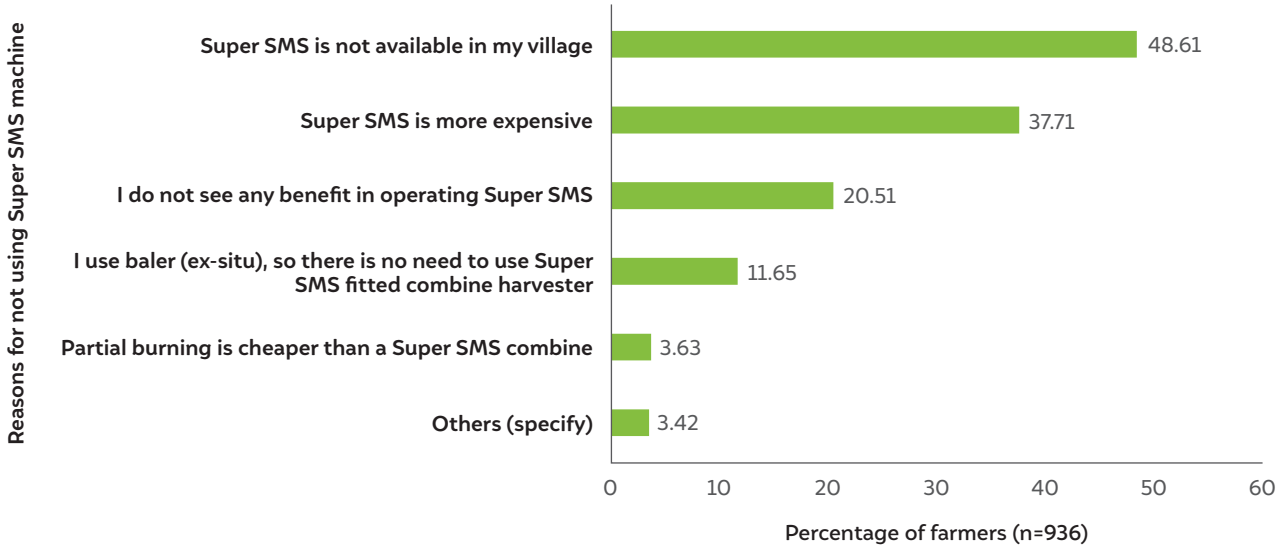
Recognising this, back in 2018, the Punjab government passed a mandate for farmers to use only the combine harvesters that are attached to the Super SMS. Despite the promotion by state actors, almost 64 per cent of the surveyed farmers used combine harvesters without a Super SMS attached in 2022. Additionally, 20 per cent of them responded that they were unaware of the state mandate. Agricultural experts and officials are of the view that these figures could be even higher. During our field visits, we observed a tendency among farmers to not recognise partial burning as burning. In fact, many farmers identify it as residue management. When asked about their reasons for not using a Super SMS, nearly 49 per cent

of farmers reported that they did not have access to Super SMS–attached combine harvesters in their village (Figure 12). Further, 38 per cent of them also felt that using a Super SMS–attached combine harvester would be expensive. Based on our interactions with the farmers, adding a Super SMS will cost INR 500–800 extra per acre when compared to partial burning.

Farmland becomes a black patchwork in the case of complete burning of paddy residue.

Charred patches along with golden standing stubble are visible in the case of partial burning.

Figure 12 Limited access and high operating cost hinders the use of Super SMS in Punjab



Source: Authors' analysis

CEEW's Harsha in conversation with a spokesperson from a cooperative society on how farmers value personal connections over digital platforms to access the rental CRM machines.

Image: Srishti Jain/CEEW

5. Does Punjab's in-situ CRM strategy need recalibration?

Since 2018, the union and Punjab governments have promoted in-situ methods as go-to solutions to manage crop residue. In this section, we break down Punjab's experience in accelerating the deployment of in-situ methods and the satisfaction levels of farmers.

Nearly 58% of surveyed farmers practised in-situ CRM in Kharif 2022.

5.1 Half of Punjab's surveyed farmers used in-situ machines to manage paddy stubble in Kharif 2022

Our survey found that 58 per cent of farmers use some type of in-situ method to manage paddy straw in Kharif 2022 (see Figure 10). However, nearly half of them opted for partial burning before operating in-situ CRM machines. The proportion of farmers who adopted in-situ methods without partial burning was higher than the state-level average of 28 per cent in medium- and low-burn districts. Notably, in the low-burn category, higher adoption of in-situ methods was observed in Jalandhar at 55 per cent (see Annexure A2).

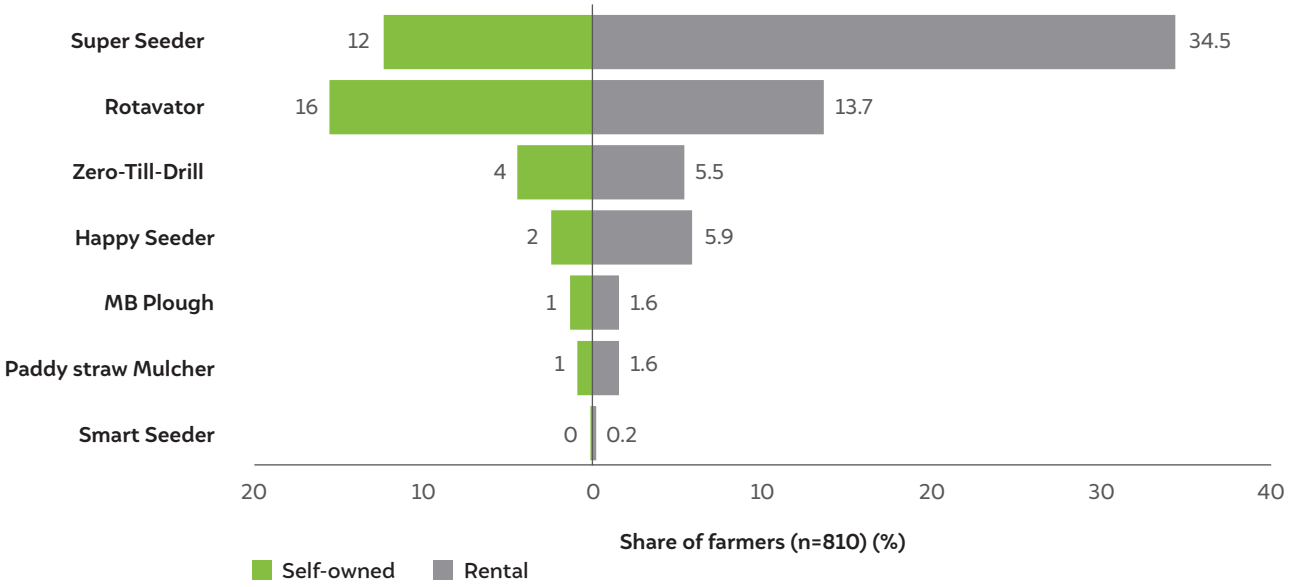
In the medium-burn category, Ludhiana and Patiala reported higher adoption of in-situ methods, with 31 and 33 per cent of farmers acknowledging its use the previous year, respectively. Although the practice of complete burning was on the lower end in medium-burn districts, an additional one-third of farmers practising in-situ methods burned the loose straw partially before operating the CRM machine. This combination of partial burning and in-situ CRM was more pronounced in high-burn districts, ranging from 33 per cent in Bathinda to as high as 54 per cent in Sangrur. All the surveyed high-burn districts reported lower usage of in-situ CRM compared to the state-level average.

While Punjab still has a long way to go to achieve zero stubble burning, our field interactions with agricultural officials revealed some of the initiatives that were being taken at the district level to improve access to and information on CRM machines. For instance, Patiala has developed a district directory of CRM machines that contains information such as owner's name, mobile number, village and block name and ownership category to support quicker hiring of CRM machines.

5.2 Of all the in-situ CRM machines, the Super Seeder rules the paddy fields in Punjab

Our survey found that most farmers use the Super Seeder (46.8 per cent) for CRM, followed by the Rotavator (29.3 per cent), Zero-Till-Drill (10 per cent), and Happy Seeder (8.3 per cent) (Figure 13). Among the surveyed districts, the Super Seeder was the most popular in Sangrur, followed by Patiala, Ludhiana, and Jalandhar. Incidentally, the practice of partial burning in these districts was also on the higher end, except in Jalandhar.

Figure 13 Punjab primarily used the Super Seeder and Rotavator to manage paddy stubble in 2022



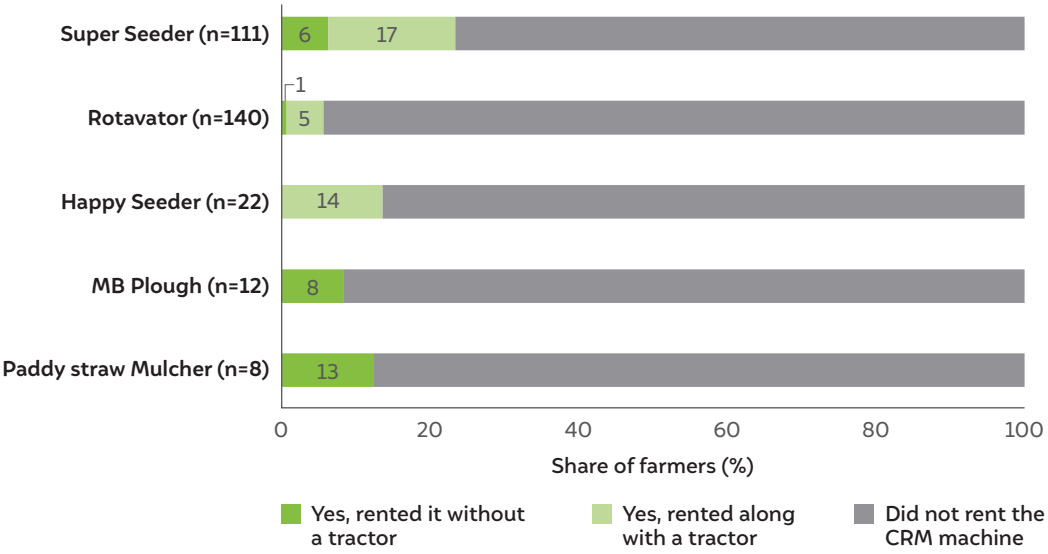
Source: Authors' analysis

5.3 Individually owned CRM machines were seldom rented out to earn additional income

We enquired about the active rental of individually owned machines. Among the surveyed farmers who own CRM machines, on average, just 13 per cent of them rented out their machines in Kharif 2022. While more than 75 per cent of them rented their CRM machines through their friends and family, for the rest, farmers directly approached owners to hire the machines. While the practice of renting out machines was at its maximum among Super Seeder–owning farmers, presumably due to the prevailing demand, the overall percentage still stood low at 23 per cent.

Estimates indicate that individually owned Super Seeders can cover 13.5 lakh hectares (half of the area sown with non-basmati paddy in 2022) in Punjab if optimally used through self-operation and a rental model for 20 days in a season (see Figure 9). Further, this approach can contribute to additional income. For instance, as per our survey, farmers charged between INR 1,600–2,500 per acre when renting out their Super Seeder. This is slightly higher than the government-recommended rate of INR 400–500 per hour or INR 1600–2000 per acre (DoAFW Punjab 2020; Babushahi Bureau 2020). We also observed that over 37 per cent of Super Seeder–owning farmers found it expensive to run the machine due to rising diesel costs. Additional income earned through renting should be leveraged to cover the running costs in such cases.

Figure 14 On average, only 13% of the farmers rented out their CRM machines for additional income

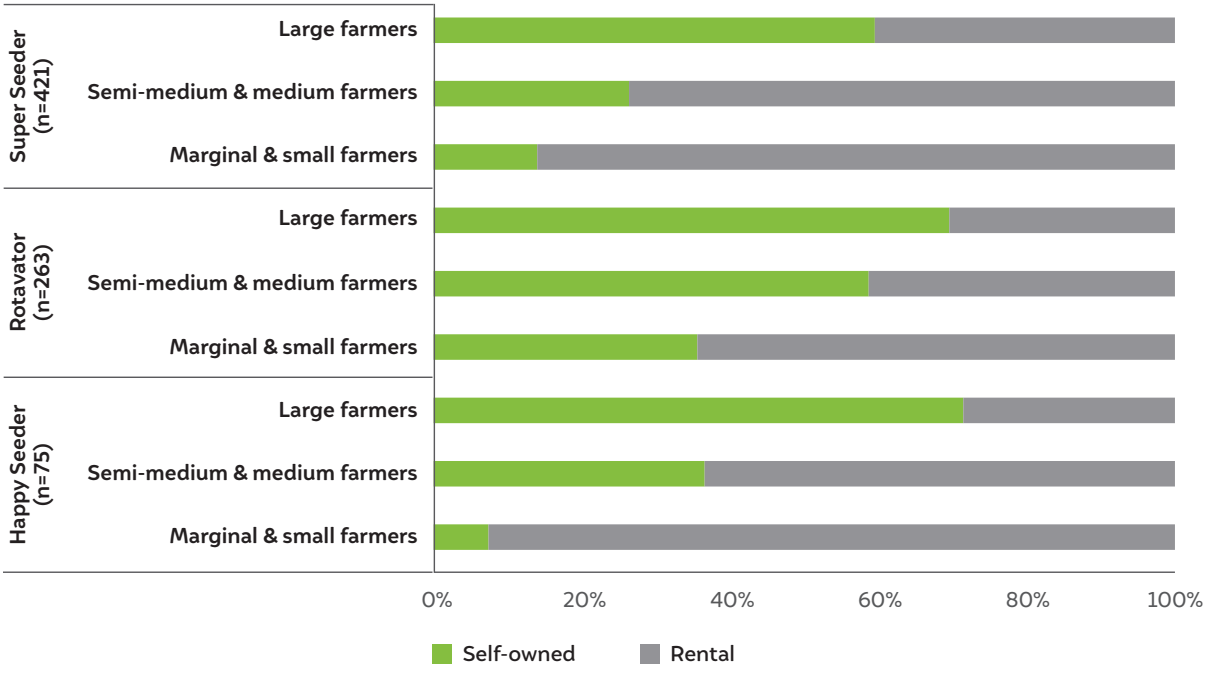


Source: Authors' analysis

5.4 Renting popular CRM machines was common among small and marginal farmers

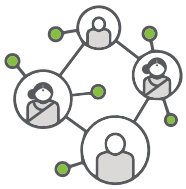
We observed that small and marginal farmers preferred renting CRM machines, while large farmers preferred owning them (Figure 15). This is because farmers in the smaller landholding categories find it difficult to cover the upfront cost of INR 1.5–3 lakh, depending on the type of CRM machine, despite the availability of a 50 per cent subsidy (MoAFW 2023). However, in the case of large farmers, our field interactions indicated that owning the machine was linked to prestige. Large and affluent farmers were often reluctant to hire machines from others. These factors nudge farmers in the large landholding category to opt for ownership (Kurinji and Prakash 2021).

Figure 15 Renting CRM machines is common among small and marginal farmers



Source: Authors' analysis

5.5 Farmers mostly preferred their immediate social networks to rent CRM machines



Farmer-to-farmer networks and cooperative societies are the most popular choices to access rental CRM machines.

We enquired about the preferred channels for accessing rental CRM machines.[9] Of the 489 surveyed farmers who rented CRM machines such as the Super Seeder, Happy Seeder, and Rotavator in Kharif 2022, nearly 82 per cent reported reaching out to nearby fellow farmers who were friends or relatives to rent the machines. Notably, the second most popular option, chosen by 12 per cent of farmers, was accessing rental machines through nearby cooperative societies. Of this, 8 out of 10 farmers relied on friends or relatives for machines through cooperative societies. This underscores the significance of personal connections in obtaining rental machinery.

In contrast, only 3 per cent of farmers sought rental machines from CHCs operated by farmer producer organisations, panchayats, or registered farmer groups. It is worth mentioning that even those who did approach CHCs obtained the machines from friends or relatives associated with the CHCs. Few farmers mentioned having obtained information about rental machines during panchayat meetings, emphasising the role of community gatherings as crucial platforms for disseminating such information.

These findings signify that farmers primarily rely on their farmer-to-farmer networks and cooperative societies to access rental CRM machines. Besides, the limited involvement of CHCs calls for revisions in their functioning and improvement in information dissemination regarding rental machinery access for timely CRM.

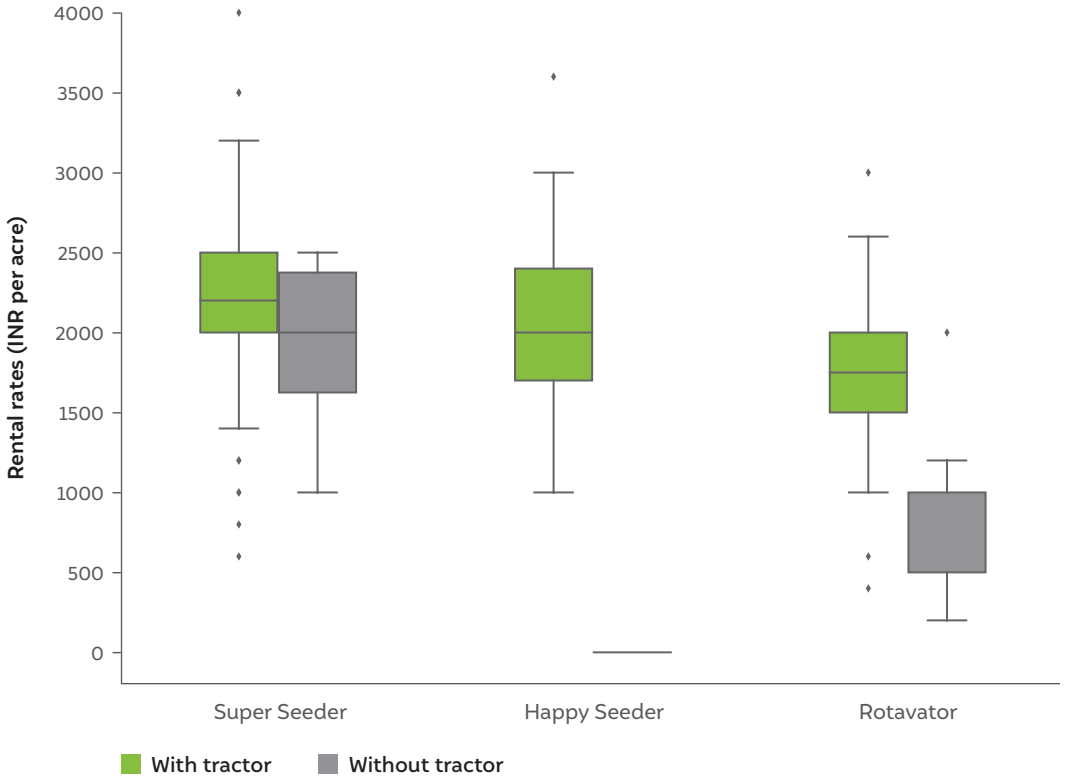
5.6 Renting CRM machines along with a tractor is more common

We found that farmers, on average, spent over INR 2,243, INR 1,992, and INR 1,736 per acre in rental charges while renting the Super Seeder, Happy Seeder, and Rotavator, respectively, from fellow farmers along with a tractor (Figure 16). A handful of farmers who accessed cooperative-owned machines were charged minimal rates as notified by the agricultural department. Rental rates were marginally lower when renting without a tractor. Regardless, renting CRM machines along with tractors remained more common in Punjab. For instance, in the case of the Super Seeder, 61 per cent of farmers who owned tractors below 50 HP or did not own any tractor chose to rent a Super Seeder along with a tractor due to HP limitations. This is because operating a Super Seeder effectively requires a tractor with an HP ranging between 55 and 75 (Pandhu 2021). Surprisingly, even among the remaining farmers, more than half who owned tractors over 50 HP opted to rent a Super Seeder along with a tractor instead of relying solely on their high-HP tractors.

During our interviews with agricultural officials, we were informed that the smooth operation of a Super Seeder requires a tractor equipped with a double clutch (Pandhu 2021) and a multi-gearbox system with low, medium, and high gears. The choice of gears to operate the Super Seeder depends on the straw load. These features are usually absent in older tractors. Additionally, to avoid the maintenance cost of tractors, some farmers prefer renting CRM machines along with tractors.

9. While accessing the rental characteristics, we mainly relied on survey responses of the three most used machines – Super Seeder, Rotavator, and Happy Seeder to avoid compromising the statistical significance.

Figure 16 Farmers spent INR 800–2,500 per acre on average while renting CRM machines



Source: Authors' analysis

Note: None of the surveyed farmers reported renting Happy Seeders without a tractor in our survey.

5.7 Promotion of mobile applications such as i-Khet for renting CRM machines needs a reboot

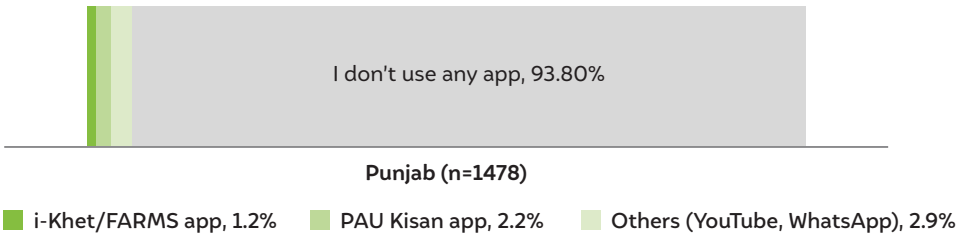
The state action plan of the Punjab Pollution Control Board sets a target and focused agenda to enhance the adoption of i-Khet Punjab, a mobile application developed by the Punjab Remote Sensing Centre (PRSC) to facilitate the rental services of farm machinery. The action plan aimed to have 65,000 machines registered on the platform by 30 November 2023, up from 42,475 as of 31 March 2022. Additionally, the plan directed all group-A officers of the Department of Agriculture to adopt one CHC each to increase the utilisation of machines (Government of Punjab 2022a).

However, when we asked farmers who rented CRM machines in Kharif 2022, only one reported having used the digital platform i-Khet Punjab. Surprisingly, the majority of farmers still rely on traditional methods, such as contacting nearby fellow farmers when renting farm machinery, rather than adopting the government-promoted digital solution. This raises concerns about farmers' reluctance to use this digital solution.

We also interviewed agricultural officials from different districts to identify the barriers to the usage of the i-Khet mobile application. The reasons are twofold. First, many farmers are unaware of the existence of the app and its benefits. As of September 2023, the app has had only 10,000+ downloads. In our survey, nearly 94 per cent of the farmers stated that they do not actively use any agriculture-related mobile applications (Figure 17). Only 1 per cent of surveyed farmers mentioned their use of the i-Khet or FARMS app, and another 2 per cent were using the PAU Kisan app. Close to 3 per cent use apps such as WhatsApp, YouTube,

and Facebook to access agricultural information. Second, i-Khet has limited acceptance among farmers as it does not align with their behavioural expectations. For instance, the app currently requires farmers to share personal information such as Aadhaar number, landholding category, address, GPS location and contact number (see Annexure A4). In contrast, other service provider apps, such as Urban Company, do not request such personal data. This results in reluctance among farmers who are technophobic and concerned about the privacy of their data. Additionally, officials from the agricultural department informed us that during the camps organised to increase awareness around i-Khet, some farmers were dependent on their tech-savvy family members to install and use the app.

Figure 17 Over 94% of farmers in Punjab do not use any agriculture-related mobile applications



Source: Authors' analysis

Given the constraints associated with the use of the i-Khet app, districts such as Patiala have made the details of CHCs and machine availability publicly accessible on their district directory portal. Patiala has also developed a WhatsApp business account to share auto-replied messages containing specific information, such as the list of available CRM machinery, the list of cooperative societies' machinery, along with their contact details, Google Play Store link for the i-Khet mobile application, the link to the application for the CRM machine subsidy, and block-wise contact details of relevant officials.

While such initiatives are encouraging, they often remain unstructured and outdated and result in discontinuation over time. To overcome this, the i-Khet app should be made farmer-friendly. The Punjab Pollution Control Board and the agriculture department officials need to organise periodic camps to break the behavioural barriers and encourage more farmers to use the i-Khet app. Such all-in-one platforms can facilitate booking services quickly as well as saving time and effort.

6. Are farmers satisfied with in-situ CRM methods?

CEEW team in conversation with a farmer from Ludhiana regarding the trainings received in operating the Super Seeder for straw management.

In this section, we delve into farmers' experiences with the use of CRM machines and the resulting satisfaction levels among farmers. We also assess the implications of their satisfaction levels on their willingness to use technology in the upcoming seasons.

6.1 Renting a well-maintained CRM machine on time is challenging

While majority of farmers (83 per cent) confirmed the timely availability of rental machines, our survey revealed that nearly 9 per cent did not receive the rental machines on time. Almost 7 per cent mentioned that they faced challenges in acquiring the machine due to high demand, and a few farmers complained that the machines they received were not in good condition.

6.2 Adoption of standard operating procedures while using in-situ methods is missing

Nearly 20 per cent of farmers who experienced a drop in wheat yields and pest attacks believe that it was due to the use of CRM machines.

Studies by research institutions suggest that the use of in-situ machines reduces the cost of sowing, water use, and fertiliser inputs in the long run. For example, Punjab Agricultural University's package of Rabi practices prescribes that if wheat is sown using the Happy Seeder continuously for three years, 20 kg urea per acre can be saved from the fourth year onwards (Table 4). This perceived usefulness of in-situ machines is pivotal in determining farmers' satisfaction levels. However, in our interactions with the farmers, we found that there were concerns surrounding the decline in wheat productivity as a result of using these alternatives. Further, pest attacks were among the biggest barriers to the sustained adoption of in-situ farm implements. Nearly 20 per cent of farmers who experienced a drop in wheat yields and pest attacks believe that it was due to the use of CRM machines.

Typically, the use of in-situ methods should be accompanied by changes in sowing practices and the application of irrigation, pesticides, fertilisers, and rodent control measures (Table 4). For instance, using the Happy Seeder or Super Seeder requires using an extra 5 kg per acre seed sowing rate than what is recommended for conventional sowing. We enquired if farmers followed the recommended changes in their crop production process while sowing wheat using machines such as the Super Seeder, Happy Seeder, or Rotavator. A significant majority (77 per cent) of farmers practising in-situ methods reported not modifying their cultivation practices and following the traditional approach. However, 23 per cent acknowledged that they had modified their production process – altering fertiliser doses, followed by adjusting the irrigation application timing and seed sowing rates. A few farmers also reported making changes to pesticide dosage and application timing. Half of the farmers who had altered their cultivation process did not observe a drop in wheat yields or pest attacks.

These findings highlight the continued lack of awareness among farmers. Predictably, over 93 per cent of in-situ CRM users admitted to not having received any training on using the in-situ machines. Only seven per cent had received training, primarily from their fellow farmers and, in some cases, through the agricultural department's extension programmes and from the machine manufacturers. While the government focuses on facilitating information education and communication activities among farmers, most information handouts, pamphlets, and farmer sensitisation programmes stop at just communicating the ill effects of stubble burning and available alternatives. Information disseminated must also include a checklist of best practices that need to be followed and input cost savings that the farmers can realise through sustained adoption.

Table 4 Changes required while using in-situ CRM methods

Crop production process	Changes required in the case of in-situ methods (using the Super Seeder or Happy Seeder)
During paddy crop production	The last irrigation for the paddy crop should be planned in such a way that moisture remains in the soil at the time of wheat sowing. To do so, apply the last irrigation **two weeks before harvesting**.
While harvesting	Use a **combine harvester fitted with Super SMS** to spread paddy straw uniformly on the field for the proper working of the Super Seeder/Happy Seeder.
Seed sowing rate	Generally, follow **5 kg higher seed per acre** than what is recommended for conventional sowing.
Sowing time	If pink stem borer/rice ear cutting caterpillar damage is observed in the previous paddy crop, **avoid sowing wheat in the month of October**. However, this contradicts the recommendation prescribed for conventional sowing. In the conventional method, sowing of long-duration wheat varieties can be commenced from the fourth week of October to save them from high temperatures near maturity. This is because delayed sowing causes a gradual decline in the yield of wheat due to heat stress.
Fertiliser application	Follow a similar approach to conventional sowing. However, if wheat is sown with the Happy Seeder continuously for three years, reduce 20 kg urea per acre from the fourth year onwards.
Irrigation	When wheat is sown with the Happy Seeder, in light-textured soil, apply first irrigation 25–30 days after sowing and in medium-to-heavy textured soils apply irrigation 30–35 days after sowing. In the case of wheat sown with the Super Seeder, apply irrigation as recommended for wheat cultivated using conventional methods. Apply irrigation after taking the rainfall forecast into account.
Pest/rodent/weed control	Regularly monitor wheat crop sown in straw-managed fields in November–December to identify problems related to insects, pests, diseases, or rodents, and use the recommended practices for their management. Use recommended pre- and post-emergence herbicides to control weeds in the case of crops sown with the Happy Seeder or Super Seeder.

Source: Authors' compilation; Package of practices for Rabi crops 2022–23.

Agricultural departments and KVKs must organise round-the-year trainings to ensure sustained adoption of CRM methods.

Image: Harsha Arya/CEEW

7. Can ex-situ CRM methods gain traction among farmers?

In this section, we synthesise farmers' perspectives on managing agricultural residue through ex-situ methods. We examine the current state of ex-situ practices in the surveyed districts, compare costs with in-situ methods, and explore farmers' first-hand experiences with ex-situ techniques.

Crop biomass collection by pastoral communities for fodder is a growing trend in northern districts such as Amritsar, Gurdaspur and Jalandhar, and in certain pockets of Rajasthan.

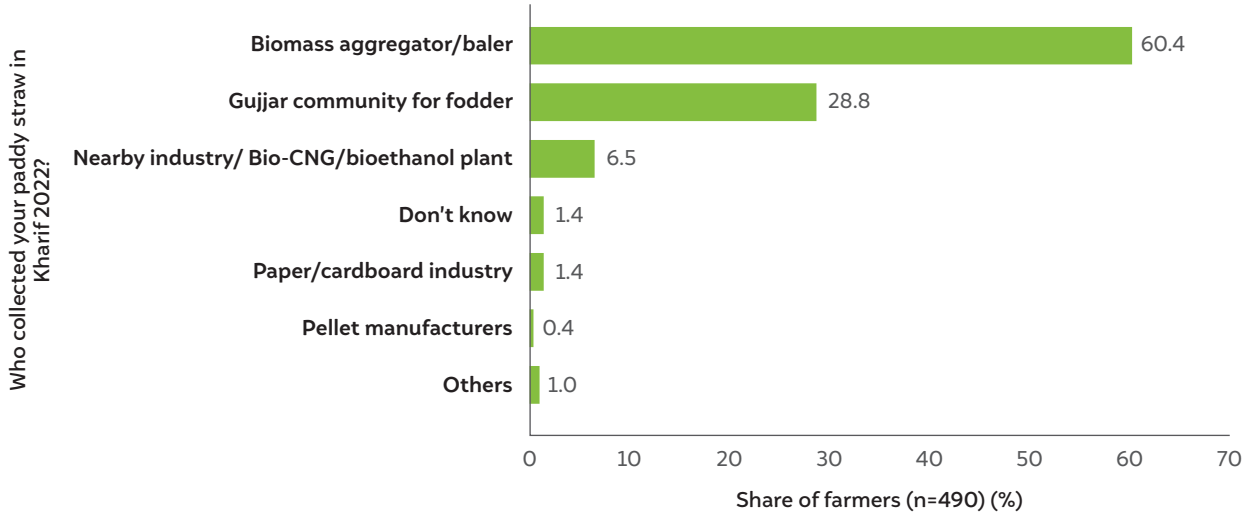
7.1 Biomass collection through aggregators dominates the ex-situ ecosystem

The government's proactive measures, including the establishment of 11 biomass-based power plants (with a total capacity of 97.50 megawatts), one agro residue–based compressed bio-gas (CBG) plant, and one ethanol-based plant, coupled with the goal to replace 20 per cent of coal with paddy straw or paddy straw pellets in brick kilns, have propelled ex-situ CRM as an emerging method. This approach involves baling the straw and transporting it from farms to end-users for energy generation or animal fodder.

In our survey, nearly 33 per cent of farmers opted for ex-situ methods to clear stubble. Biomass aggregators are the predominant service providers, with 60 per cent of ex-situ farmers stating that they rely on these individuals to remove straw from their fields (Figure 18). The Gujjar community follows closely behind, as reported by 29 per cent of farmers. Only eight per cent of farmers mentioned that nearby industries collect their straw directly.

While the use of paddy straw as fodder is traditionally less preferred due to its high silica content, residue collection by Gujjar/pastoral communities for fodder is a growing trend in northern districts such as Amritsar, Gurdaspur and Jalandhar, and in certain pockets of Rajasthan (Annexure A2). Gujjars prefer paddy straw, especially during winter months, mainly because of the high cost and limited availability of green fodder and wheat residue. The pastoral community make the paddy straw rumen gut-friendly by rationing the rice straw with protein and other readymade minerals. Further, grazing their animals daily further improves their digestibility.

Figure 18 Nearly 60% of ex-situ farmers cleared stubble using biomass aggregators



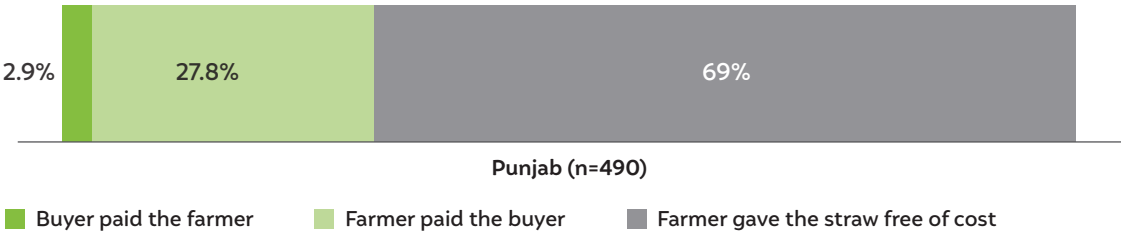
Source: Authors' analysis

7.2 Lack of formal purchase contract weakens trust among farmers

Contrary to the popular belief that the ex-situ CRM provides additional income, only 2.9 per cent of farmers (n=490) following ex-situ methods received payments of about INR 1,200 per acre when selling their stubble (Figure 19). The remaining farmers either gave the stubble free of cost or paid around INR 1,000 per acre to clear the stubble.

When enquired about the agreement format, seven per cent of the ex-situ practising farmers mentioned that a formal contract was signed between them and the buyer when procuring the paddy stubble. Over 26 per cent stated that the buyer reached out by telephone/in person, but no formal contract was signed before procurement. Close to 67 per cent cited that there was no formal contract but the transaction was based on mutual trust since the buyer was from the farmers' networks. When asked if formalising the procurement contract would benefit them, 65 per cent of farmers agreed that it would ensure credibility. However, 28 per cent did not believe that it would benefit them and about 7 per cent said that a procurement contract was not required as they had known the buyer for many years.

Figure 19 Nearly 70% of ex-situ farmers gave the straw free of cost



Source: Authors' analysis

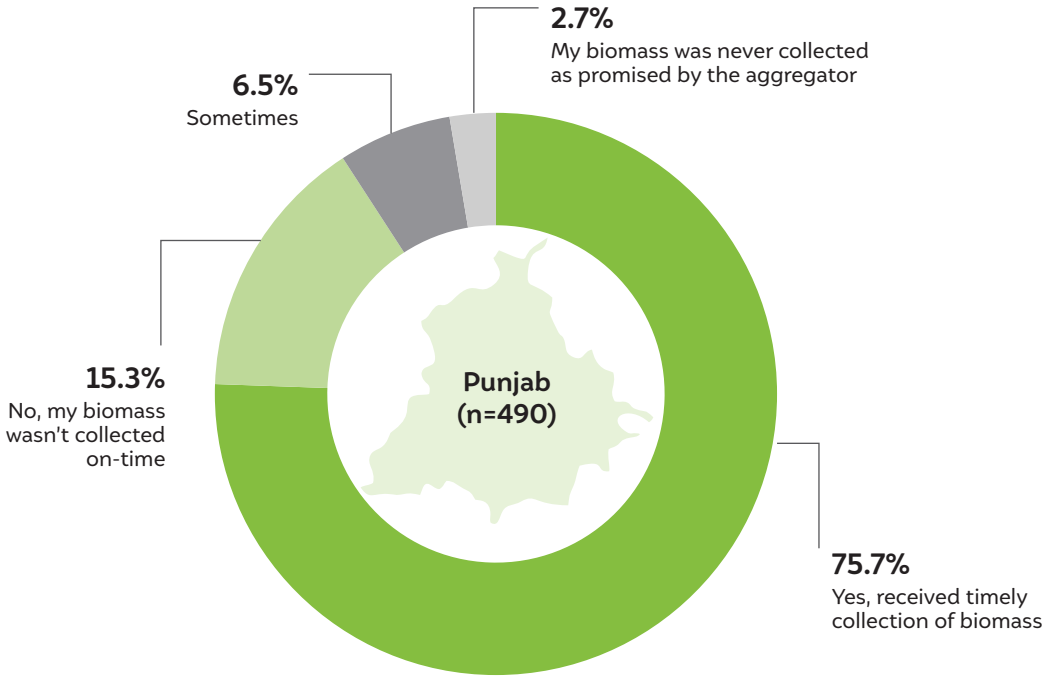
Note: The responses from n=490 ex-situ CRM practising farmers are considered.

7.3 Delay in residue collection and not receiving payments for crop stubble results in dissatisfaction among farmers

The majority of buyers reached out to farmers to procure stubble only during the peak season in October and November (88 per cent). Just about 10 per cent of farmers reported getting purchase orders from stubble buyers somewhat early in September. A marginal 2 per cent reported receiving purchase requests in July and August.

While 76 per cent of the ex-situ practising farmers claimed that the buyer cleared the residue on time from the fields, nearly 15 per cent said that they faced delays in residue collection (Figure 20). Additionally, close to 3 per cent complained that their residue was never removed as promised by the buyer.

Figure 20 Almost 76% of ex-situ CRM practising farmers claimed on-time clearance of paddy residue from the field



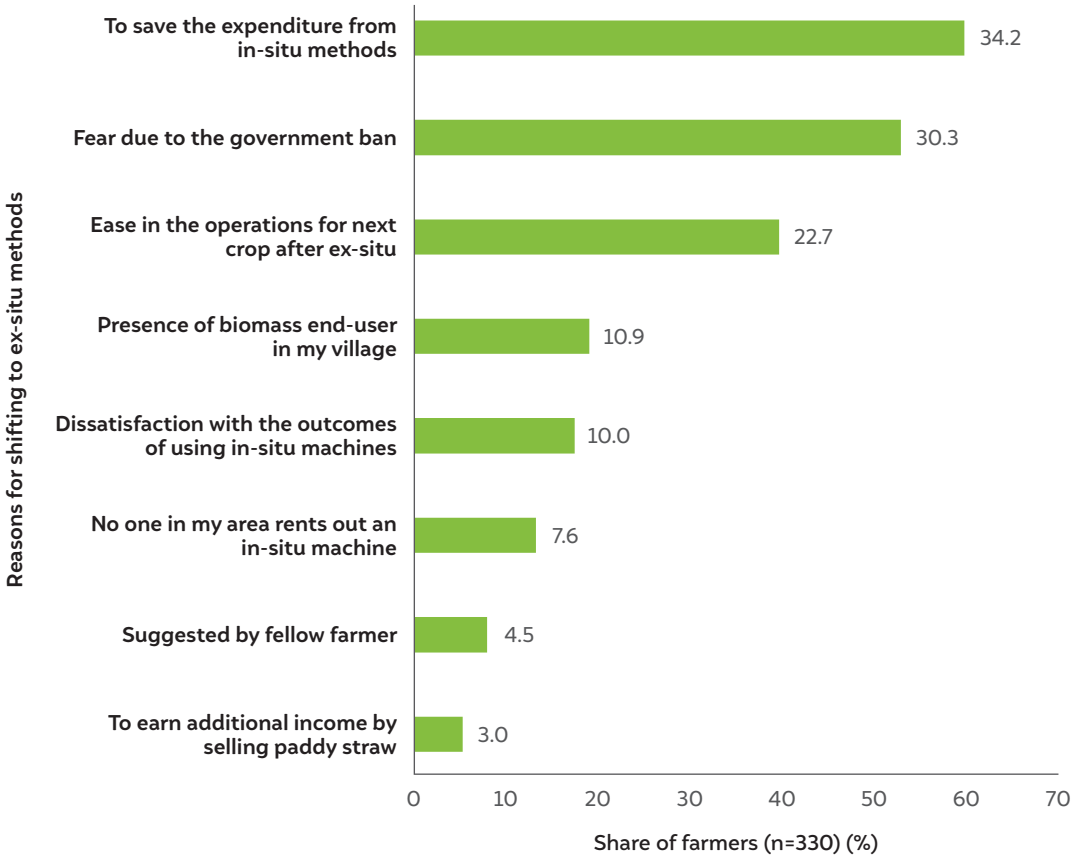
Source: Authors' analysis

Note: The responses from n=490 ex-situ CRM practising farmers are considered.

When asked if the farmers were satisfied with the adoption of ex-situ methods, a surprising majority (91 per cent) said yes. The rest of the dissatisfied farmers quoted not receiving payments for paddy residue as the major reason for their dissatisfaction, followed by experiencing a delay in residue collection.

We observed that nearly 67 per cent of the ex-situ CRM practising farmers were those who had initially followed in-situ methods or burning and shifted to ex-situ methods in the recent past. The majority made the shift due to the ease in prepping the land for the next crop and to cut down the expenditure necessary for in-situ CRM methods (Figure 21).

Figure 21 Farmers made the shift to ex-situ CRM to avoid the cost incurred with in-situ CRM methods



Source: Authors' analysis

Despite the challenges faced by a few farmers, nearly 86 per cent agreed that they would continue with ex-situ methods in Kharif 2023. Consequently, the 2023 Kharif season involved more balers in action (Mohan 2023; Nibber 2023). However, a shortage of baling machines and biomass end-users continues to remain a significant barrier in the sector.

While farmers are in favour of ex-situ methods, agricultural experts and officials argue that ex-situ CRM cannot be a long-term sustainable solution. While ex-situ CRM can solve the problem of air pollution in the near term, lifting the straw from the field will degrade soil health in the long run.

8. Conclusion and policy recommendations for the sustained adoption of CRM methods

CEEW's Kurinji interacting with Ashish Kumar from Verbio India on the large scale storage and heavy machinery needed to source biomass from farmlands within a timeframe of 20 days.

It is evident that the policies implemented by the union and state governments since 2018 to stop stubble burning have yielded encouraging results in rural Punjab. However, there remains much scope for policy action in both the agriculture and energy sectors to shift towards zero stubble burning. Our study, based on a survey of about 1,500 farmers, presents a multidimensional assessment, offering critical insights for a nuanced understanding of the situation. It also recommends targeted actions to ensure the sustained adoption of zero-burn methods over time.

8.1 Strategies to promote varietal diversification

Announcements such as the procurement of summer *moong* at MSP if the farmer sows PR 126 in the same field after harvesting *moong*, increased farmers' interest in short-duration varieties.

Ensure strict inspections to discontinue the sale and circulation of PUSA 44 seeds. Our survey confirms that PUSA 44 continues to be preferred by farmers due to its high yield, resistance to pests, and fewer broken grains when shelled. It yields approximately 32 quintals per acre against 30 quintals of the early-maturing varieties such as PR 126 and PR 121. However, PUSA 44's long gestation period and high residue generation result in more burning. Considering the environmentally detrimental traits of PUSA 44, the government de-notified the variety in October 2023. However, it remains in circulation primarily through private seed companies. Therefore, district-level agricultural officers should amp up inspections of private seed dealers, distributors and producers to phase out the variety completely.

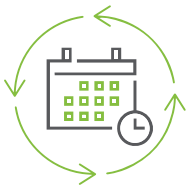
Promote seed breeding and retention of popular PR varieties to meet the state's seed demand. Our survey highlights that PR 126 (followed by PR 121) gained momentum in almost all districts except the border districts such as Amritsar and Gurdaspur. Our interactions with agricultural officials and ground reports also show a rise in the popularity of new varieties – PR 128 in Amritsar, Gurdaspur, and Patiala; PR 131 and PR 114 in Tarn Taran, Firozpur, Faridkot, and Bathinda; and PR 131 in Hoshiarpur, Kapurthala, Jalandhar, Pathankot, SAS Nagar, and SBS Nagar (Express News Service 2023b). The last two sowing seasons saw a quick emptying of seed stock in the case of PR 126 and many farmers had to resort to less popular varieties. Therefore, state authorities need to assess the emerging trends to support recognised institutions such as the Indian Council of Agricultural Research, agricultural universities, government seed farms, the National Seed Corporation, and state seed agencies to produce breeder seeds on a large scale. Further, farmers must be encouraged to sign up to develop certified seeds with the Punjab State Seed Certification Authority. This way, farmers will have access to good quality seeds and retaining these seeds will cater to the needs of forthcoming seasons.

Additional incentives to promote the adoption of short-duration varieties among reluctant farmers. The introduction of incentives, such as the procurement of summer *moong* at MSP if the farmer sows PR 126 or basmati in the same field after harvesting *moong*, increased farmers' interest in short-duration varieties (Kamal 2022; Dey 2022). Continuing such incentives will likely persuade PUSA-growing farmers to discontinue the long-duration variety.

8.2 Strategies for wider adoption of in-situ methods

Develop a compendium listing the standard operating procedures and best practices while using CRM methods. Despite years of promotion and awareness drives, our survey highlights the prevalence of misapprehensions among farmers regarding pest attacks and wheat productivity when using CRM machines. Further, only a small share of farmers reported adopting changes to the crop production process after using CRM machines. While Punjab Agricultural University's (2023) biennial report, *Package of Practices of Rabi crops*, covers a few modifications needed for the crop production process after using in-situ machines, a consolidated practitioner's guide is yet to be created for farmer consumption.

Organise year-round training to ensure sustained adoption of CRM methods. Training workshops by KVKs and agricultural departments are mostly scheduled close to the tail-end of the Kharif season (September), when the farmers are busy with harvesting and selling produce in local *mandis*. Such training workshops should be curated to cover not just zero-burn CRM methods but also the changes needed in the cultivation practices of Rabi crops.



Newer additions of CRM machines on a year-on-year basis strengthen the possibility of making the existing stock of Happy Seeders and Super Seeders redundant.

Make the i-Khet Punjab app farmer-friendly. While the Punjab government has ambitious targets to increase the machines registered on the i-Khet app and thereby scale up the rental model of CRM machines, our survey finds that only 1.2 per cent of farmers are aware of the existence of the app. Additionally, the download rate stands at a mere 10,000+ as of September 2023. The app's current version collects extensive personal data, including Aadhaar number and land ownership, making it less attractive among farmers. To resolve this, the PRSC must initiate an app upgrade to incorporate a responsive design that can improve user experience and boost engagement. Following a farmer-centric design strategy, the upgrade should cater to farmers' needs, preferences, and behaviours. Further, the automatic alert features should be enabled to send personalised notifications covering the health and cost benefits of CRM methods, improvement in soil health, and savings made on agricultural inputs.

Codify an evaluation framework to include only machines with demonstrated success in the CRM subsidy scheme. When the central government launched its flagship CRM scheme in 2018, the Happy Seeder was promoted as the ideal solution to manage stubble on the field. With new machine variants arriving in the market every year, Punjab has included such machines under the CRM scheme over time. This includes the addition of Super Seeders in 2020, followed by Smart Seeders in 2022. Further, in 2023, the Punjab government approved the proposal to subsidise Surface Seeders, a new machine developed by Punjab Agricultural University that can be attached to a combine harvester to ensure simultaneous paddy harvesting and wheat sowing (The Indian Express 2023).

Our study estimates that the current stock of Happy Seeders and Super Seeders is sufficient to manage the total area under non-basmati cultivation. Our survey further establishes the rising popularity of Super Seeders among farmers and how other machines, such as the Happy Seeder, Smart Seeder and Super SMS, have limited acceptance. Therefore, newer additions of machines on a year-on-year basis strengthen the possibility of making the existing stock of Happy Seeders and Super Seeders redundant. Rectifying this would require setting up an evaluation committee that can assess the efficacy of these machines and farmers' preferences from the cost and yield perspectives through pilots before being included in the subsidy scheme. The findings should also proactively be made available in the public domain and readily accessible by farmers. This will facilitate farmers adopting these technologies.

8.3 Strategy to promote ex-situ methods in regions that have biomass end-users

Accessibility, affordability, and cost-effectiveness of CRM alternatives are significant determinants to replacing conventional burning.

Set a price floor for raw biomass and biomass-based products to ensure a minimum viable price. We find that the ex-situ CRM method is highly acceptable among farmers as it provides additional income and does not necessitate altering the crop production process. While the ex-situ sector is slowly growing in Punjab, only 2.9 per cent of the 33 per cent of farmers following ex-situ methods received payments of about INR 1,200 per acre while selling their stubble. The remaining farmers either gave the stubble free of cost or paid around INR 1,000 per acre to clear the stubble. Our conversations with biomass end-users revealed that the minimum affordable cost for sourcing biomass would vary across the end-user category. While big players such as coal-fired power plants can afford prices as high as INR 8,000–10,000 per tonne for biomass pellets,[10] other industries and bio-CNG plants prefer bales at INR 2,500 or lower (NTPC n.d.).

As per the latest CRM guidelines released by the Ministry of Agriculture & Farmers' Welfare (MoAFW) in July 2023, the cost of collected biomass is to be mutually agreed upon by the farmer group/aggregator and industry based on the market condition (MoAFW 2023). However, setting a price floor for raw biomass and biomass-based products will ensure a minimum viable price for farmers to not undertake stubble burning. To this end, we recommend that the state institute a state-level task force under the Punjab Energy Development Agency to benchmark prices. India is already undertaking similar initiatives. For instance, the Power Ministry announced plans to benchmark biomass pellet prices in 2023 and the Haryana government is likely to notify a commonly determined rate for paddy straw procurement.

While the adoption of in-situ and ex-situ methods has become common among farmers in recent years, accessibility, affordability, and cost-effectiveness are still significant determinants to replacing conventional burning. Even among farmers following the in-situ method, nearly half followed partial burning in Kharif 2022 to ensure the smooth operation of CRM machines. While Punjab has a long way to go in becoming a zero-stubble-burning state, better use of existing methods and targeted outreach can accelerate its journey in the coming seasons.

10. About 1 tonne of pellets is produced from 1.3 tonne of residue through densification.

Acronyms

CBG	compressed bio-gas
CHC	custom hiring centre
CRM	crop residue management
ICAR	Indian Council of Agricultural Research
KVK	Krishi Vigyan Kendra
MoAFW	Ministry of Agriculture & Farmers Welfare
MSP	minimum support price
PAU	Punjab Agricultural University
PEDA	Punjab Energy Development Agency
PPS	Probability proportional to size
PRSC	Punjab Remote Sensing Centre
SMS	Straw management system

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Annexures

Annexure A1
Categorisation of Punjab's districts using farm fires

We categorised 22 districts of Punjab into three classes: high-burn, medium-burn, and low-burn districts, based on the number of fire counts per unit area (1,000 acres) under non-basmati cultivation. Districts with fire count intensity in the first tertile (< 33.3 percentile value) are considered low-burn, districts in the middle tertile are considered medium-burn, and districts in the highest tertile (> 66.6 percentile) are considered high-burn.

Table A1 Categorisation based on the number of open fires per 1,000 hectares under non-basmati cultivation

Categories	District	Area under non-basmati in 2020 ('000 hectare)	Fire counts during paddy residue burning in 2020	Fire counts per 1,000 hectares under non-basmati cultivation in 2020
Low-burn	Pathankot	28.6	24	0.839161
	SBS Nagar	60.9	199	3.267652
	Hoshiarpur	77.4	431	5.568475
	Rupnagar	37.3	251	6.729223
	SAS Nagar	26.7	201	7.52809
	Jalandhar	153.1	1,720	11.23449
	Gurdaspur	157.4	1,936	12.29987
Medium-burn	Kapurthala	109.7	1,507	13.73747
	Ludhiana	247.6	3,698	14.93538
	Fatehgarh Sahib	76.1	1,379	18.12089
	Patiala	213.3	4,722	22.13783
	Muktsar	180.4	4,762	26.3969
	Amritsar	87.7	2,389	27.24059
	Faridkot	108.2	3,299	30.48983
High-burn	Tarn Taran	130.7	4,026	30.80337
	Moga	177.9	5,599	31.47274
	Sangrur	244.8	8,805	35.96814
	Firozpur	167.3	6,110	36.52122
	Bhatinda	167.2	6,954	41.59091
	Mansa	109.4	4,624	42.26691
	Fazilka	70.1	2,992	42.68188
	Barnala	99.3	4,274	43.04129

Source: CEEW compilation

Note: *33.3 percentile – 13.72; **66.6 percentile – 30.799

Dark shade indicates the randomly sampled districts in each burn category.

Annexure A2
How did farmers manage paddy stubble in Kharif 2022?

Table A2 CRM methods followed by farmers at district-level

District	Number of surveyed farmers (n)	Share of farmers (n=1478) (%)						
			In-situ CRM		Ex-situ CRM			
		Complete burning	Partial burning + In-situ CRM	Partial burning + In-situ CRM	Gave it to a baler	Gave it to Gujjar community for fodder	Gave it to a nearby industry	Fodder for own cattle
Amritsar	140	13.6	25.0	23.6	6.4	22.9	0.0	26.4
Bathinda	126	18.3	32.5	24.6	23.0	9.5	0.8	7.9
Fatehgarh Sahib	132	5.3	36.4	28.8	36.4	3.0	1.5	3.0
Fazilka	129	23.3	31.0	10.1	38.0	2.3	4.7	7.0
Firozpur	135	23.0	28.1	18.5	31.9	1.5	0.0	12.6
Gurdaspur	136	8.1	19.1	22.1	8.8	30.9	0.7	28.7
Jalandhar	137	4.4	19.7	54.7	13.9	16.8	0.7	10.9
Ludhiana	137	5.1	36.5	33.6	24.8	6.6	1.5	8.0
Patiala	134	19.4	36.6	31.3	20.9	1.5	0.0	2.2
Sangrur	136	16.2	54.4	22.1	9.6	1.5	1.5	2.2
SBS Nagar	136	4.4	6.6	41.2	47.1	11.8	1.5	10.3

Source: Authors' analysis

Note: The percentage of farmers adopting different CRM practices does not add up to 100 per cent since farmers tend to adopt more than one type of CRM method.

Annexure A3
Maximum area that can be covered by CRM machines

Assuming a maximum daily run time of eight hours, a Happy Seeder can cover 3.2 hectares in a day, whereas the Super Seeder can work through 2.4 hectares. Assuming a maximum window of 20 days between the harvest of paddy and the sowing of wheat, we estimate that one Happy Seeder can cover a maximum of 64 hectares of farmland in a season. A single Super Seeder, in contrast, can cover 48 hectares of land in one season. Multiplying the total number of machines with the area a single machine can cover in one season (20 days), we found that the existing stock of 43,452 Super Seeders and 13,560 Happy Seeders can be used to manage 8.68 lakh hectares and 20.86 lakh hectares, respectively. Together, these machines can cover 100 per cent of the non-basmati paddy sown fields in Punjab if deployed at maximum capacity.

Annexure A4

What determines the adoption of zero-burn CRM methods among farmers?

In this study, logistic regression was chosen as the method for analysing the likelihood of farmers burning crop residue. In the analysis, the dependent variable is whether farmers burn crop residue, which is a binary outcome (yes or no). Logistic regression is designed particularly to model and analyse binary or categorical outcomes, making it appropriate for this research question.

Table A3 Logistic regression to understand the factors that determine the possibility of farmers following stubble burning

Dependent variable: Farmer will burn crop residue (1=Yes, 0=No)	Odds ratio	Std. error	p-value
Did you use self-owned machinery for crop residue management? (1=Yes; 0=No)	18.1	0.4	0.00***
Did you use rented machinery for crop residue management? (1=Yes; 0=No)	19.3	0.3	0.00***
Did you grow the PUSA paddy variety? (1=Yes; 0=No)	2.2	0.2	0.0007 ***
Did you grow PR paddy variety? (1=Yes; 0=No)	1.01	0.2	0.95
Did you use in-situ techniques for crop residue management? (1=Yes; 0=No)	0.00007	0.6	0.00 ***
Did you use ex-situ techniques for crop residue management? (1=Yes; 0=No)	0.002	0.4	0.00 ***
Age (base category: 18–35)			
36–52	0.7	0.2	0.37
53–69	0.4	0.3	0.03 *
> 70	0.4	0.5	0.07
Landholding category (base category: semi-medium farmer)			
Marginal farmer	0.4	0.5	0.13
Small farmer	1.6	0.3	0.11
Medium farmer	1.7	0.2	0.07
Large farmer	2.83	0.4	0.011***
Log-likelihood	–305.1914 (df=21)		
Pseudo R squared	0.696		

Source: Authors' analysis

Note: ***p < 0.01, **p < 0.05, and *p < 0.1.

Annexure A5

Screenshot of i-Khet Punjab app showing the details required for registration

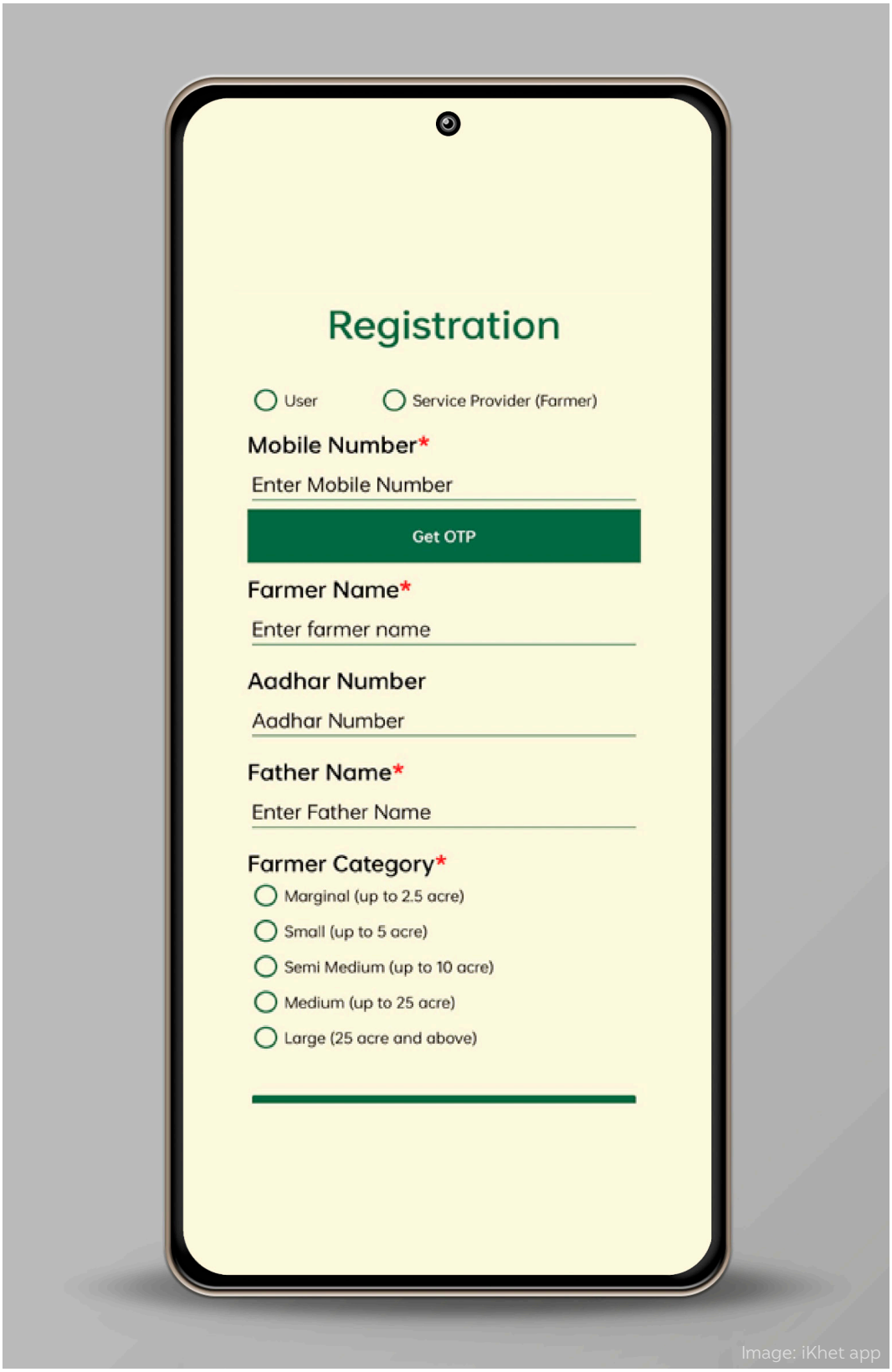

Image: iKhet app

The authors

Kurinji Kemanth
kurinji.selvaraj@ceew.in I @KurinjiSelvaraj

Kurinji Selvaraj is a Programme Associate in CEEW's Clean Air team. Her research revolves around solving air pollution and crop residue burning in northern India. Kurinji holds an Energy and Environmental Engineering undergraduate degree from Tamil Nadu Agricultural University, Coimbatore.

Ramandeep Singh
rdatwal.iabm@gmail.com I @RamanAtwal20

Ramandeep Singh was a Research Analyst at CEEW. His work focused on crop residue burning in Punjab. His research interests include behavioural economics and examining public policies. Ramandeep holds a doctorate in Agribusiness from the Institute of Agribusiness Management, Bikaner.

Sneha Maria Ignatious
sneha.ignatious@ceew.in I @SnehaIgnatious

Sneha Maria Ignatious is a Research Analyst in CEEW's Clean Air team. She uses data-driven approaches to draw insights and generate evidence to drive policies on air quality management. Sneha holds a master's degree in Green Energy Technology from Pondicherry University.

COUNCIL ON ENERGY, ENVIRONMENT AND WATER (CEEW)

ISID Campus, 4 Vasant Kunj Institutional Area
New Delhi - 110070, India
T: +91 (0) 11 4073 3300

info@ceew.in | ceew.in | @CEEWIndia | ceewindia

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