



# Understanding Adoption, Preferences and Performance of Agricultural Machinery in Punjab









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# Executive Summary

Punjab faces a recurring environmental challenge each year as large volumes of paddy straw are burned due to the narrow 15–20 day window between rice harvest and wheat sowing. This tight turnaround, combined with high labor and operational constraints, makes residue burning the quickest field clearing option for many farmers, with serious implications for public health and soil health.

This report analyzes patterns of adoption and use of crop residue management (CRM) machinery and conventional agricultural machinery across 18 districts of Punjab, highlighting how machine choice, ownership models and local conditions shape residue management outcomes. Government financial support—particularly through capital subsidies—has played a central role in accelerating the uptake of CRM machines. However, the analysis shows that farmers continue to invest heavily in conventional, everyday machinery such as rotavators.

A notable shift has also been observed in ownership patterns, with an increasing number of individual farmers purchasing machines privately to ensure timely access during the short and intensive planting season. In contrast, reliance on machinery owned by farmer groups or shared Custom Hiring Centers is declining. This trend is largely attributed to the rapid deterioration of shared equipment due to intensive use, combined with unclear responsibility for routine maintenance. As a result, farmers increasingly favor personally owned, everyday machinery that offers reliability and immediate availability.

At harvest time, farmers prefer to use standard combine harvesters over those with built in straw choppers or Straw Management System (SMS). Standard combines cover substantially more area—over three times as much as SMS equipped machines—because they operate faster, have lower running costs, and do not require high horsepower tractors. Given the narrow harvesting window,





farmers prefer to complete grain harvest quickly and deal with straw management afterward, instead of handling both tasks at the same time.

For managing the straw left after harvest, the Super Seeder is the most popular choice. This heavy duty machine chops the residue, incorporates it into the soil and sows the next crop in a single pass, making it particularly effective in heavy and moist soil conditions. In contrast, in areas with lighter, sandier soils, farmers prefer to use the Zero Till Drill, which is simpler to operate and more cost effective.

The Happy Seeder, an earlier-generation technology, has been losing popularity because it leaves a thick mulch layer on the soil surface, which can exacerbate pest pressure and interfere with crop establishment. As a result, adoption is gradually shifting towards newer alternatives, such as the Smart Seeder, which address many of these limitations.

Some farmers use balers to compress the remaining straw into bundles that can be removed from the field altogether. While this practice is gradually expanding, it is financially viable only when farms are located close to factories, biomass power plants or other facilities that can purchase the baled straw.

To improve the effectiveness of residue management machinery overall, government support needs to become more targeted and context specific. Rather than promoting the same set of machines uniformly, subsidies should align with local conditions—supporting heavier machinery in areas with stronger soils and lighter equipment in districts with sandy or fragile soils. At the same time, it is critical to invest in local repair and service networks to extend the working life of existing machines. Finally, strict enforcement of the existing mandate requiring all combine harvesters to be fitted with functional straw chopping systems remains essential to ensure effective residue management at the harvesting stage.



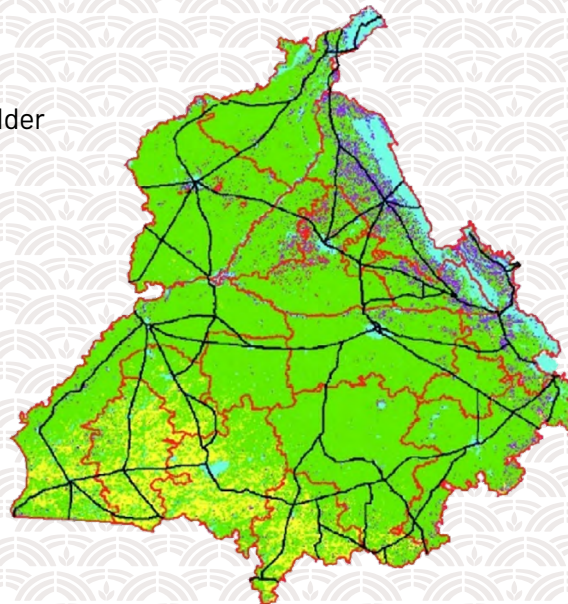


# 01. Introduction

Punjab, one of India's leading agricultural states, faces a major environmental challenge due to crop residue burning, particularly during the post-harvest period of the paddy season. The state's agriculture is dominated by a rice-wheat cropping system, which leaves farmers with only a narrow window between paddy harvest and wheat sowing. This short interval, typically lasting 15–20 days, often compels farmers to burn paddy straw to rapidly clear fields for the subsequent crop.

**Figure 1: Spatial distribution of major kharif crops in Punjab**

- Rice
- Maize/Scane/Fodder
- Cotton
- Vegetable
- Non Agrl



The annual generation of approximately 20 million tonnes of paddy straw poses a significant ecological challenge in Punjab. The traditional practice of crop residue burning results in the loss of valuable biomass and contributes to severe environmental pollution and public health risks. To address this issue, in 2022, The Nature Conservancy launched the PRANA (Promoting Regenerative and No-Burn Agriculture) project with the objective of promoting sustainable Crop Residue Management (CRM) practices that allow farmers to manage residues without resorting to burning.

<sup>1</sup>Press Information Bureau (Nov. 19, 2025). Paddy Harvesting Season 2025 Concludes With Significant Reduction in Stubble Burning Incidents [Press release]. <https://www.pib.gov.in/PressReleasePage.aspx?PRID=2197201>



In this context, specialized CRM machinery plays a crucial role in addressing residue-burning challenges. Equipment such as the Happy Seeder, Super Seeder, Smart Seeder and Surface Seeder enables direct sowing of wheat into fields containing residual paddy straw, facilitating in situ management of crop residues. Additionally, the adoption of combine harvesters fitted with a Super Straw Management System (SMS) has been encouraged to ensure uniform distribution of chopped straw during harvesting, which enhances subsequent field preparation and residue management efficiency.

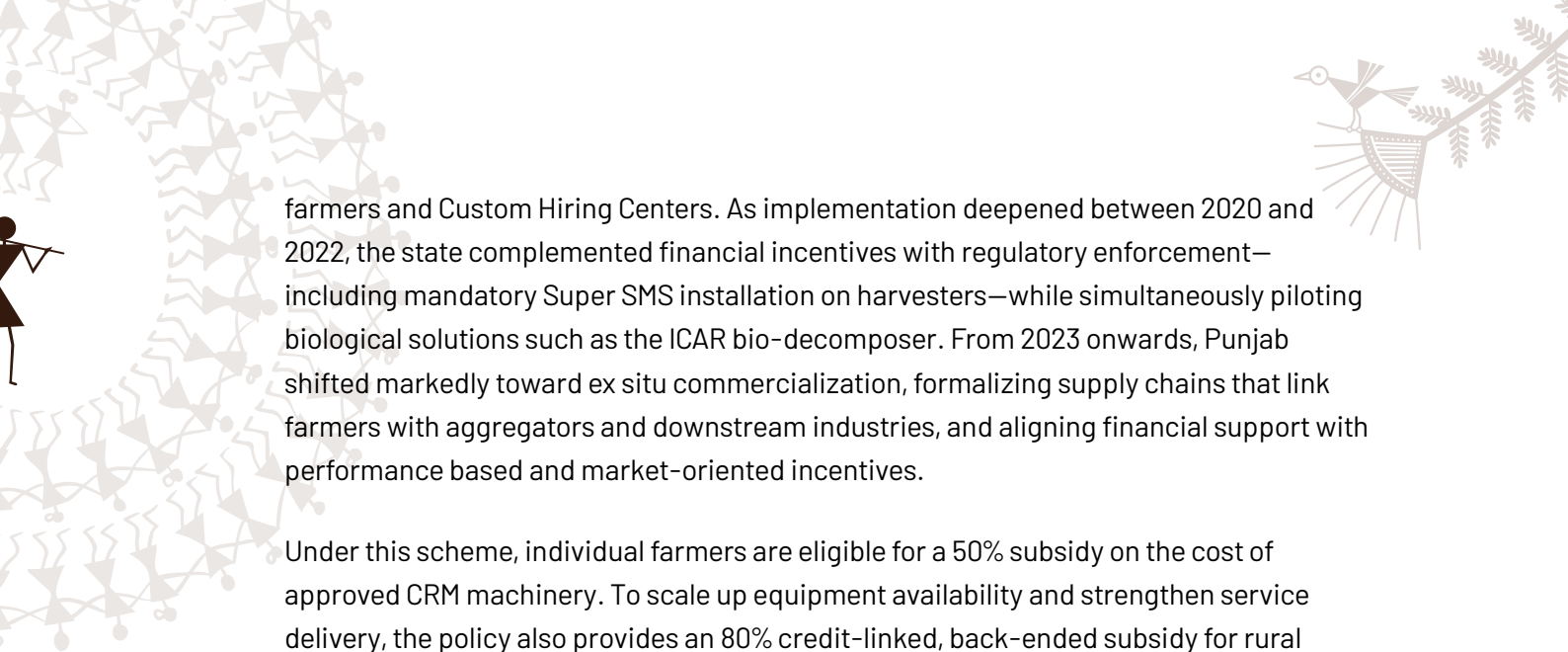
A comparative analysis of fire-incident data reveals a substantial transformation in agricultural residue management practices in Punjab in recent years. From a peak of 71,304 incidents recorded in 2021, the number declined sharply to just 5,114 incidents during the 2025 kharif season—an approximate 92.8% reduction over four years.<sup>1</sup> This significant decrease underscores the combined impact of strengthened policy measures and availability of CRM machinery, resulting in the growing adoption of sustainable crop residue management strategies.

The Crop Residue Management (CRM) policy, implemented under the Rashtriya Krishi Vikas Yojana (RKVY) was launched in 2018 to combat air pollution and soil degradation caused by the open burning of paddy straw across Punjab, Haryana, Uttar Pradesh, Madhya Pradesh and the NCT of Delhi. To promote the adoption of both sustainable in situ (on-field) and ex situ (off-field) management practices, the framework offers substantial financial assistance to enable farmers, entrepreneurs and service providers to adopt appropriate technologies.

Within this national framework, Punjab has emerged as a key implementation state, with its CRM scheme evolving through clearly defined phases. The initial phase (2018–19) focused on improving access to in situ machinery through capital subsidies to individual







farmers and Custom Hiring Centers. As implementation deepened between 2020 and 2022, the state complemented financial incentives with regulatory enforcement—including mandatory Super SMS installation on harvesters—while simultaneously piloting biological solutions such as the ICAR bio-decomposer. From 2023 onwards, Punjab shifted markedly toward ex situ commercialization, formalizing supply chains that link farmers with aggregators and downstream industries, and aligning financial support with performance based and market-oriented incentives.

Under this scheme, individual farmers are eligible for a 50% subsidy on the cost of approved CRM machinery. To scale up equipment availability and strengthen service delivery, the policy also provides an 80% credit-linked, back-ended subsidy for rural entrepreneurs and farmer groups establishing custom hiring centers (CHCs). In parallel, a 65% capital subsidy is extended to develop robust paddy-straw supply chains that directly connect residue collection with end-user industries such as biomass power plants and bio-ethanol facilities,<sup>2</sup> thereby reinforcing Punjab's transition toward a commercially viable residue economy.

Despite this expansion in policy scope and financial support, persistent structural barriers remain in translating these interventions into universal access on the ground. High capital costs, limited awareness and constraints related to timely availability of equipment continue to hinder widespread adoption, particularly among smallholder farmers who often lack the financial capacity for individual ownership. This machinery mapping exercise provides a comprehensive understanding of the spatial distribution and availability of CRM machinery across the state of Punjab. This evidence based assessment is important for informing more strategic deployment of resources and targeted interventions in underserved areas, helping to identify critical access gaps and strengthen the overall effectiveness of residue management efforts.

<sup>2</sup>Government of India. (2025). Crop Residue Management: Operational Guidelines 2025. Ministry of Agriculture & Farmers Welfare, Department of Agriculture & Farmers Welfare (Mechanization & Technology Division). New Delhi: Krishi Bhawan.





## 02. Study Design

A comprehensive database of available agricultural machinery was compiled across 18 of Punjab's 23 districts during 2023 and 2024. Data collection in the project villages was conducted through systematic field-level visits. In total, 4,246 villages were surveyed twice, in 2023 and 2024.

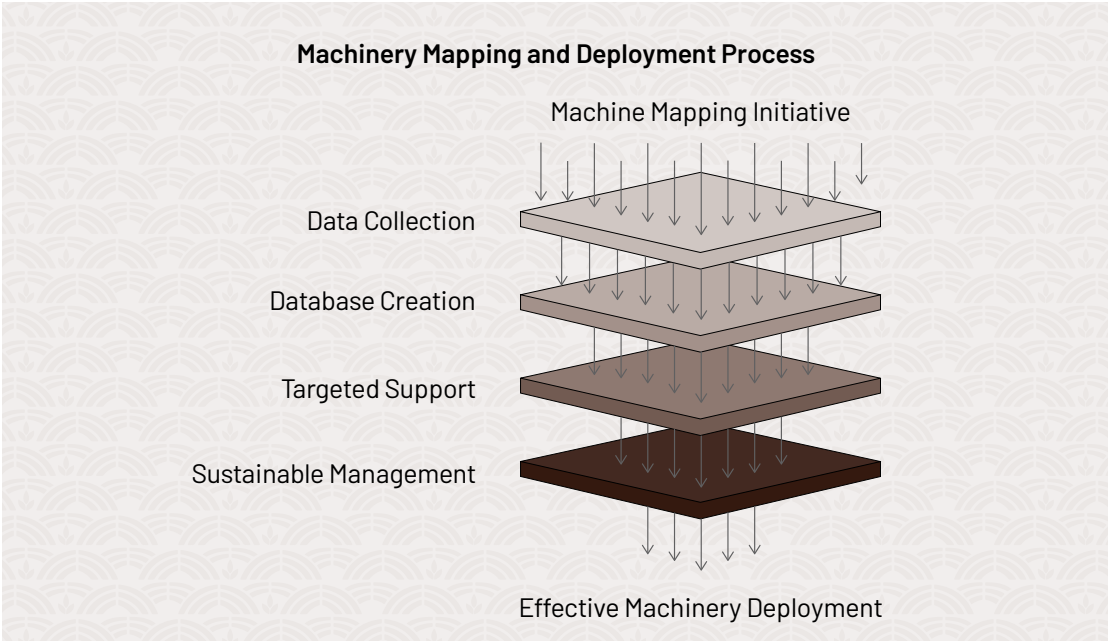
Detailed information was recorded on the availability, ownership and operational status of a wide range of agricultural machines, employed across different farming activities such as direct seeding, crop harvesting, straw management, land preparation, and both in situ and ex situ crop residue management. Machinery ownership was classified into various categories, namely individual farmer ownership, custom hiring centers (CHCs) and cooperative societies.

The machinery mapping undertaken in this study constitutes a foundational step for future phases of the PRANA project. By generating village and district level evidence on the availability and spatial distribution of CRM machinery, the dataset establishes a baseline that can be leveraged for subsequent analytical and implementation efforts. While the present study focuses on data compilation and descriptive assessment, the information generated is intended to support future targeting of interventions, including prioritization of underserved areas, optimization of machinery allocation and design of context specific support mechanisms (Figure 2). In subsequent project phases, this evidence base will enable more data driven decision making and facilitate more effective, equitable and sustainable deployment of CRM machinery in alignment with local agronomic and institutional conditions.





**Figure 2: Machinery mapping framework to inform targeted CRM interventions**



**Table 1: Overview of data collected during field surveys (2023–2024)**

|                               | Year 2023 | Year 2024 |
|-------------------------------|-----------|-----------|
| Total machine records         | 54,395    | 52,191    |
| Districts covered             | 18        | 18        |
| Villages surveyed             | 4,246     | 4,246     |
| Machines with subsidy         | 23,130    | 23,204    |
| Machines without subsidy      | 31,265    | 28,987    |
| Machines in working condition | 52,904    | 50,827    |



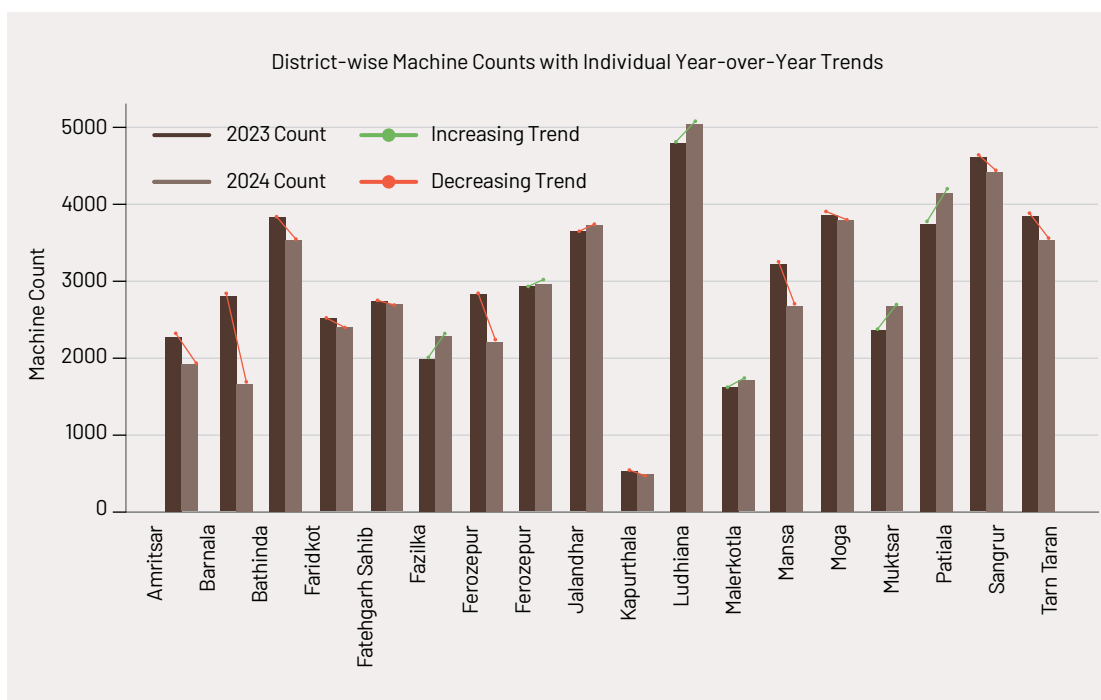


## 03. Results

### 3.1. District-level trends in reported machines (2023–2024)

A comparative analysis of survey data between 2023 and 2024 reveals a shift in the distribution of agricultural machines at the state level. The total number of reported machines declined from 54,395 in 2023 to 52,191 in 2024 with significant differences observed across some districts.

**Figure 3: District-wise machine counts in 2023–2024**



The decline in the number of machines is driven by a sharp decline in a few districts, most notably Barnala (–1,130 units) and Ferozepur (–627 units). In contrast, some districts diverged from the overall trend, with Patiala (+401), Muktsar (+295) and Fazilka (+293) recording the strongest one-year increases (Figure3).





## 3.2. The role of subsidies in agricultural mechanization

In the context of Punjab's agricultural landscape, government subsidies have become the primary catalyst for transitioning from traditional stubble burning to mechanized crop residue management (CRM). The state and central governments typically offer a 50% subsidy to individual farmers and an 80% subsidy to cooperative societies, farmer producer organizations (FPOs), and custom hiring centers (CHCs) for the procurement of specialized machinery like Super Seeders, Mulchers and Balers.<sup>3</sup> This strategic subsidization is designed to offset the high upfront costs of advanced agricultural equipment, which tend to be disproportionately high for small-scale use and remain largely unaffordable for small and marginal landholders.

To address this constraint more systematically, the Punjab government expanded this support in 2025 through a ₹500 crore action plan, introducing credit-linked capital subsidies and bank hypothecation for machines to ensure accountability and long-term use. These subsidies have effectively democratized access to technology, resulting in the uptake of over 1.5 lakh CRM machines across the state and a 93% reduction of farm fire incidents from 2021 to 2025.<sup>4</sup>

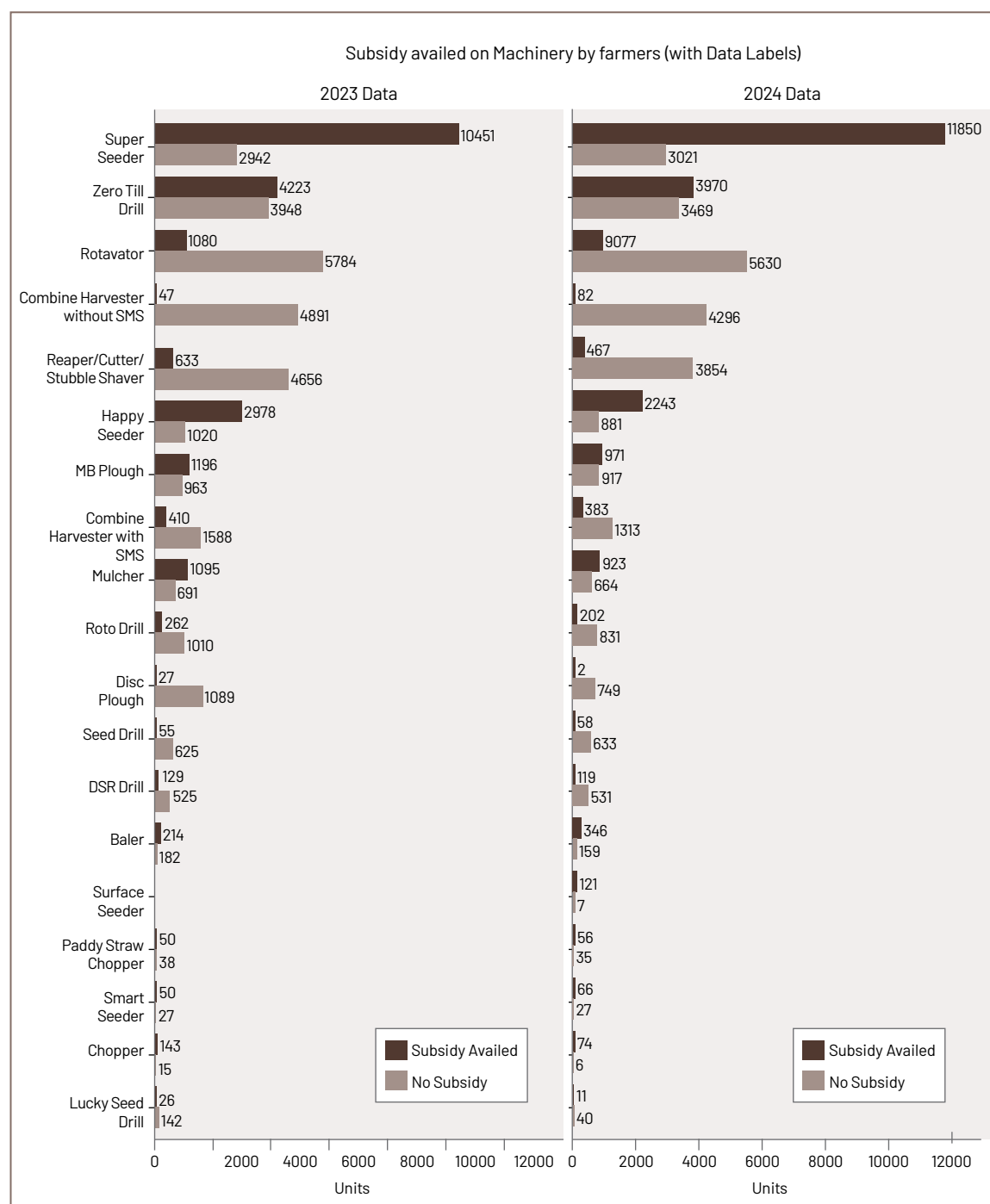
<sup>3</sup>Government of India. (2025). Crop Residue Management: Operational Guidelines 2025. Ministry of Agriculture & Farmers Welfare, Department of Agriculture & Farmers Welfare (Mechanization & Technology Division). New Delhi: Krishi Bhawan. [https://www.pau.edu/content/banner/6757\\_2.pdf](https://www.pau.edu/content/banner/6757_2.pdf)

<sup>4</sup>Kemanth, K. and Arya, H. (2024). How Can Punjab Increase the Adoption of Crop Residue Management Methods? Survey Insights From 11 Districts of the State. Council on Energy, Environment and Water (CEEW). <https://www.ceew.in/publications/how-can-punjab-adopt-crop-residue-management-methods-and-tackle-paddy-stubble-burning>





**Figure 4: Subsidies availed by agricultural machinery type**

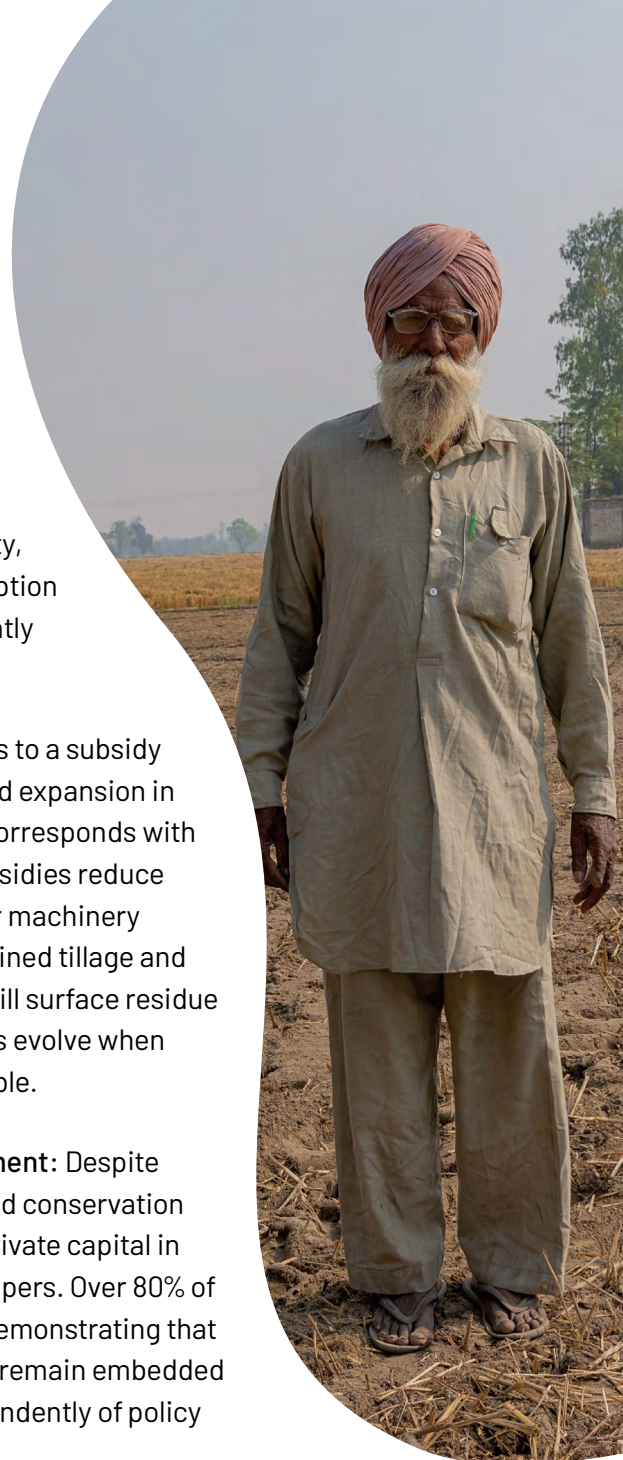


The 2023–2024 data on machinery adoption and subsidies availed reveals a clear divide in farmer behavior:

- **Private purchase of conventional machinery:** Conventional equipment such as rotavators, combine harvesters, reapers/cutters/stubble shavers and disc ploughs are typically purchased using private funds. In contrast, the adoption of advanced conservation technologies, including Super Seeders, Happy Seeders and Zero-Till Drills remains heavily reliant on targeted government subsidies.



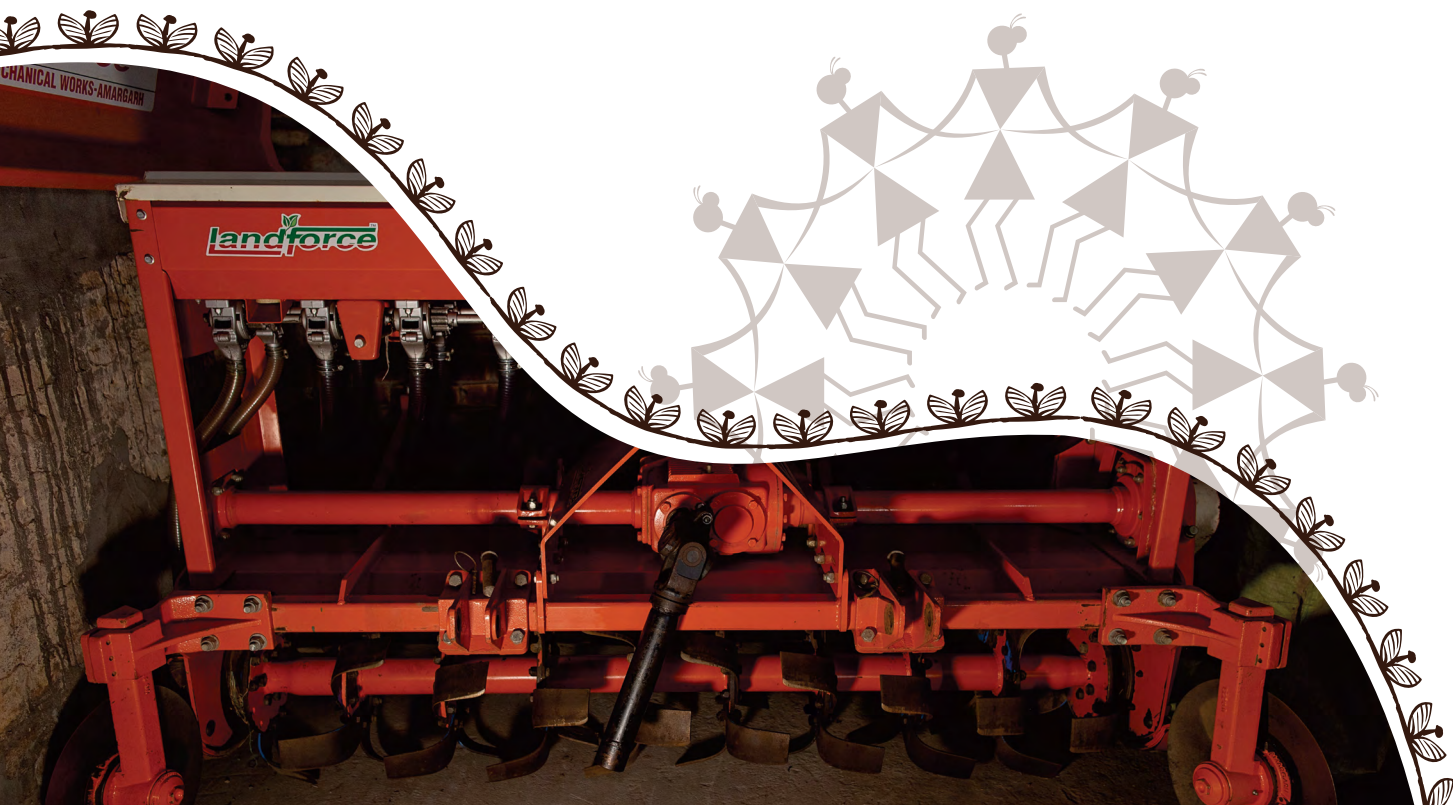
- **Subsidies drive adoption of high-cost machinery:** Financial incentives play an important role in farmers' adoption of costly equipment. The Super Seeder dominates the market, but its adoption is largely policy driven rather than market led: approximately 80% of all units purchased across both years were supported by government subsidies. This suggests that while farmers recognize the agronomic value of heavy duty, single pass residue management technologies, adoption occurs primarily when the financial risk is significantly reduced through subsidies.
- **Phasing out the Happy Seeder:** The data also points to a subsidy enabled technological upgrading behavior. The rapid expansion in the adoption of subsidized Super Seeders directly corresponds with a decline in the uptake of Happy Seeders. When subsidies reduce entry barriers, farmers exhibit a clear preference for machinery that enables active soil incorporation through combined tillage and sowing, rather than technologies based on pure no till surface residue retention. This shift reflects operational preferences evolve when higher capacity options become financially accessible.
- **Persistence of conventional, multipurpose equipment:** Despite sustained government efforts to promote specialized conservation machinery, farmers continue to invest significant private capital in multipurpose equipment such as rotavators and reapers. Over 80% of these machines are purchased without subsidies, demonstrating that conventional field preparation and residue clearing remain embedded in prevailing agronomic practices, operating independently of policy incentives.
- **Consistent preference for decoupled operations:** A consistent and deeply entrenched operational preference is also evident in harvest technology choices. Farmers continue to purchase, in large volumes, combine harvesters without a Straw Management System (SMS)—4,938 units in 2023 and 4,377 in 2024—almost entirely using private funds. In contrast, adoption of combine harvesters equipped with SMS remains substantially lower, declining from 1,998 units in 2023 to 1,696 units in 2024. This pattern may reflect a sustained preference for combine harvesters without SMS. The inclusion of SMS increases operational costs, which are typically passed on to farmers, raising the cost of harvesting and discouraging adoption. Instead, farmers prefer to separate harvesting from residue management, opting to first clear the field and subsequently manage paddy straw through specialized machinery in later operational passes. This decoupled approach allows greater flexibility and cost control when dealing with heavy and complex residue loads.



### 3.3. Ownership and status of machinery

The study also examined patterns of machinery ownership—individual ownership, cooperative society and custom hiring centres (CHCs)—along with the operational status of the machinery: in working condition, in need of major repairs or junk (Table 2). The main findings of this analysis are summarized below:

- **Individual ownership remains prevalent:** Individual ownership levels were largely stable in 2023 and 2024, with only a marginal decline of 200 machines (0.4%) in 2024. Notably, 88% of agricultural machinery in 2024 was individually owned, indicating a sustained preference among farmers for personal asset ownership rather than reliance on state-provided machinery. Individual ownership ensures round-the-clock access to equipment during critical, short-window sowing and harvesting periods. Existing subsidy mechanisms have also likely reinforced this trend by lowering entry barriers and improving the financial feasibility of private ownership.
- **Decline of the institutional/cooperative model:** The operational landscape of crop residue management is undergoing a significant transition, as evidenced by a 16.57% decline in machines managed by cooperative societies and a 32.39% drop for CHCs between 2023 and 2024. This trend suggests a gradual move away from institutional models—which often face challenges related to “collective responsibility” and maintenance—in favor of more reliable private or individual ownership. At the same time, this structural shift may have distributional implications, with uneven machinery availability at CHCs and peripheral districts facing a higher risk of localized CHC shortages and longer waiting times during the time-sensitive sowing window.
- **Modernization and fleet replacement:** A 37.14% decline in junk machinery indicates proactive fleet renewal. This suggests farmers and institutions are retiring obsolete, non-functional machinery and investing in newer, more efficient models, with the newer phases of the CRM scheme incentives likely playing a catalytic role in accelerating machinery replacement.







- **Maintenance and performance gaps in institutional assets:** Institutional owners (cooperatives and CHCs) report a significantly higher proportion of non-functional machinery compared to individual owners. In 2024, approximately 6% of machines owned by cooperative societies were non-functional, compared to only 2.3% of individually owned machines. This performance gap is largely driven by limited access to immediate repair funds and the absence of dedicated operators for shared, institutionally owned machines. In contrast, individual owners have a direct financial stake in their equipment and are therefore more likely to undertake timely preventive maintenance.
- **Emerging maintenance pressure:** The share of equipment requiring major repairs declined slightly between 2023 and 2024. Machines purchased during the 2018–2021 period of expanded subsidy coverage are now reaching the stage in their lifecycle that demands significant technical overhauls, particularly related to engines and gearboxes. This emerging pattern points to an urgent need to strengthen local, authorized service centres with advanced repair capabilities.

**Table 2: Ownership and status of agricultural machinery in 2023–2024**

| Category  | Entity/Status        | 2023   | 2024   | Trend                                                                                 |
|-----------|----------------------|--------|--------|---------------------------------------------------------------------------------------|
| Ownership | Individual owner     | 45,957 | 45,757 |  |
|           | Cooperative society  | 4,500  | 3,754  |  |
|           | CHC                  | 3,541  | 2,394  |  |
| Status    | In working condition | 52904  | 50827  |  |
|           | Needs major repairs  | 1243   | 1173   |  |
|           | Junk                 | 245    | 154    |  |

## 3.4. Operational area covered by agricultural machinery

### 3.4.1. Harvesting machinery

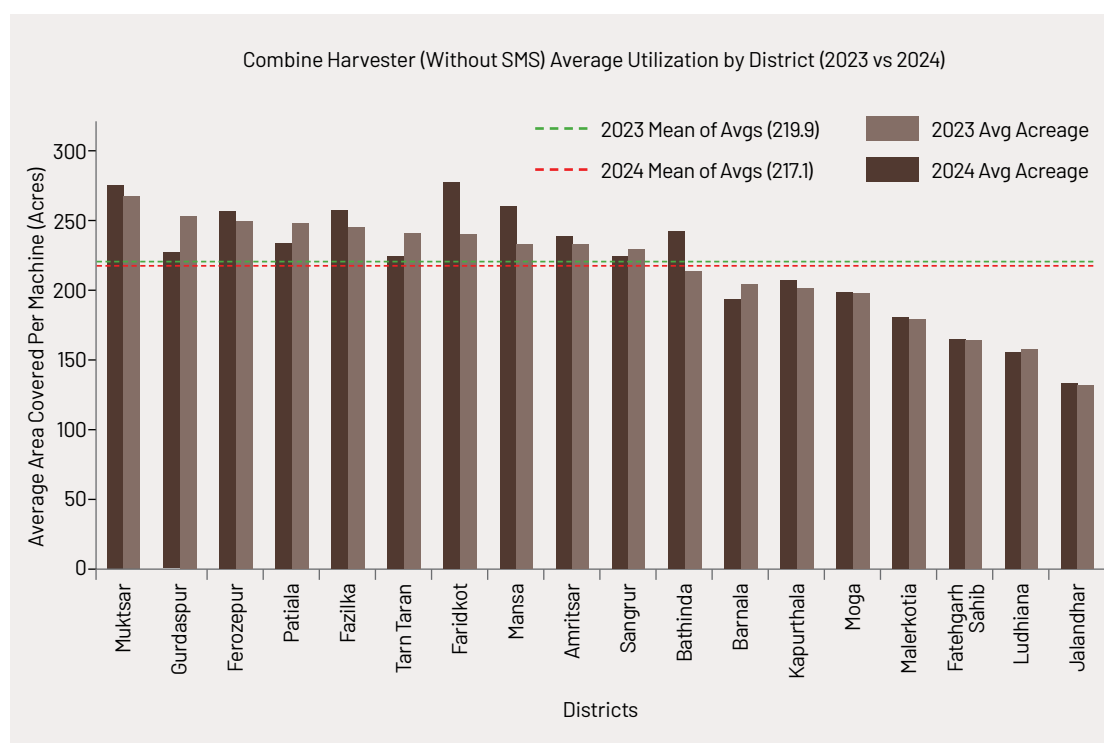
#### Combine harvester (without SMS)

A standard combine harvester without a Super Straw Management System (SMS) is designed primarily to collect grain, leaving the remaining straw deposited in dense, concentrated rows or “windrows” behind the machine. These thick piles of straw are difficult for subsequent sowing and planting equipment to cut through, often compelling farmers to resort to crop residue burning to clear the field quickly. In the absence of an SMS attachment that chops and evenly spreads the straw, fields remain cluttered with bulky stalks, creating a significant barrier to modern conservation and no-till farming practices.





**Figure 5: Average operational area covered by individual combine harvesters (without SMS)**



The analysis of the average area covered per combine harvester (without SMS) yielded the following findings:

- Decline in total area covered by combine harvesters (without SMS):** The data collected indicates that the total area covered by standard combine harvesters (without SMS) decreased from 1,151,829 acres in 2023 to 1,025,924 acres in 2024. This reduction likely reflects a shift by farmers toward SMS-equipped harvesters or alternative residue management practices. Despite the decline in total coverage, operational efficiency per machine remained largely stable, with the average area covered per machine increasing marginally from 233.2 acres to 234.6 acres across the state. This stability suggests that while the number of operations using standard combines may be decreasing, the workload and utilization intensity per machine have remained consistent.

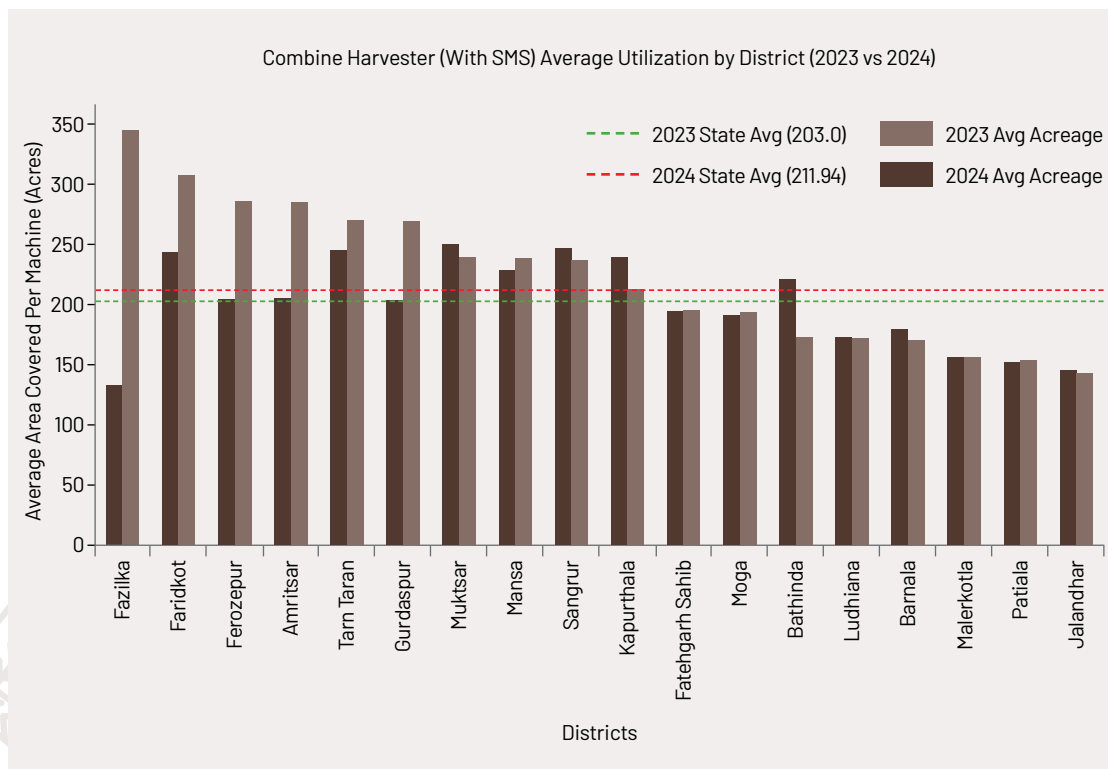


- **Operational ceiling reached by non-SMS combine harvesters:** A typical combine harvester without SMS appears to reach a natural operational ceiling at approximately 230–250 acres per season. The consistency of this range across most districts suggests that utilization is no longer constrained by demand, but rather by structural factors, particularly the limited duration of the harvest window and the physical capacity of machines and operators to cover additional area within that timeframe.
- **Muktsar and Gurdaspur are leading in operational efficiency:** Muktsar (268.4 acres) and Gurdaspur (253.3 acres) record the highest operational area covered by standard combine harvesters. Gurdaspur recorded a notable efficiency increase, indicating a substantial improvement in machine utilization. These outcomes suggest the presence of effective service delivery models and/or well coordinated machine routing and scheduling in these districts.

### Combine harvester (with SMS)

A combine harvester with a Super Straw Management System (SMS) is a specialized machine that harvests grain while simultaneously managing the leftover stalks. Unlike standard harvesters that leave clumps of straw behind, the SMS attachment chops the residue into small pieces and spreads them uniformly across the entire field. This creates a thin layer of mulch that protects the soil and allows farmers to plant their next crop immediately without needing to burn the field.

**Figure 6: Average operational area covered by individual combine harvesters (with SMS)**



The analysis of the average area covered by combine harvesters (with SMS) reveals the following key findings:

- **Increased operational efficiency in the context of a reduced fleet:** While the total area covered by SMS-equipped harvesters decreased from 404,649 acres in 2023 to 357,546.5 acres in 2024 in the surveyed area, the average area covered by each individual machine increased from 203 acres to 211.9 acres. Even though fewer machines were recorded as active in 2024 (from 1,998 in 2023 to 1,696 in 2024), the functioning fleet was utilized more intensely.
- **High regional variation:** A significant disparity was observed in the efficiency with which districts utilize SMS-equipped harvesters. On average, combine harvesters equipped with SMS cover 211.9 acres across the state. However, districts such as Jalandhar and Patiala are operating at levels well below 160 acres per machine, whereas high-performing districts like Fazilka have exceeded 340 acres per machine. This indicates that adoption levels and machine routing practices are not yet uniform across Punjab.

**Figure 6: Combine harvester with SMS**



- **Western and border belt leadership in operational efficiency:** Districts in Punjab's western and border belt—particularly Fazilka, Faridkot, Ferozepur, Amritsar and Tarn Taran—emerge as clear leaders in per-machine operational efficiency. Fazilka stands out, recording a substantial performance increase from 138 acres per machine in 2023 to 349.4 acres in 2024. This pattern likely reflects a combination of larger and more consolidated farm holdings in these regions, better-organized Custom Hiring Centres (CHCs), and more effective local enforcement and coordination, all of which may be contributing to the more optimal deployment and utilization of SMS technology in these districts.





- **Strategic policy implications:** While the efficiency of non-SMS combine harvesters appears to have reached a plateau with machines already operating near their practical capacity limits, there remains significant scope to enhance the performance of SMS equipped harvesters. Targeted capacity building and operational optimization—particularly aimed at narrowing the gap between lower-performing districts and high-efficiency leaders such as Muktsar—can yield meaningful gains. Strengthening this convergence is critical to ensuring that when farmers opt for a cleaner harvesting method, it is as timely and operationally reliable as conventional harvesting.

### 3.4.2: In situ crop residue management: Minimum tillage machinery

In situ crop residue management refers to the practice of managing and decomposing crop residue directly in the field where the crop was grown, rather than removing it from the site. Through specialized techniques like incorporation or mulching, standing stubble is either chopped and mixed back into the soil or retained on the surface as a protective mulch layer during the sowing of the subsequent crop. This on-site approach improves soil health by recycling organic nutrients, improving soil structure and retaining moisture, thereby transforming agricultural waste into a valuable input for sustainable farming.

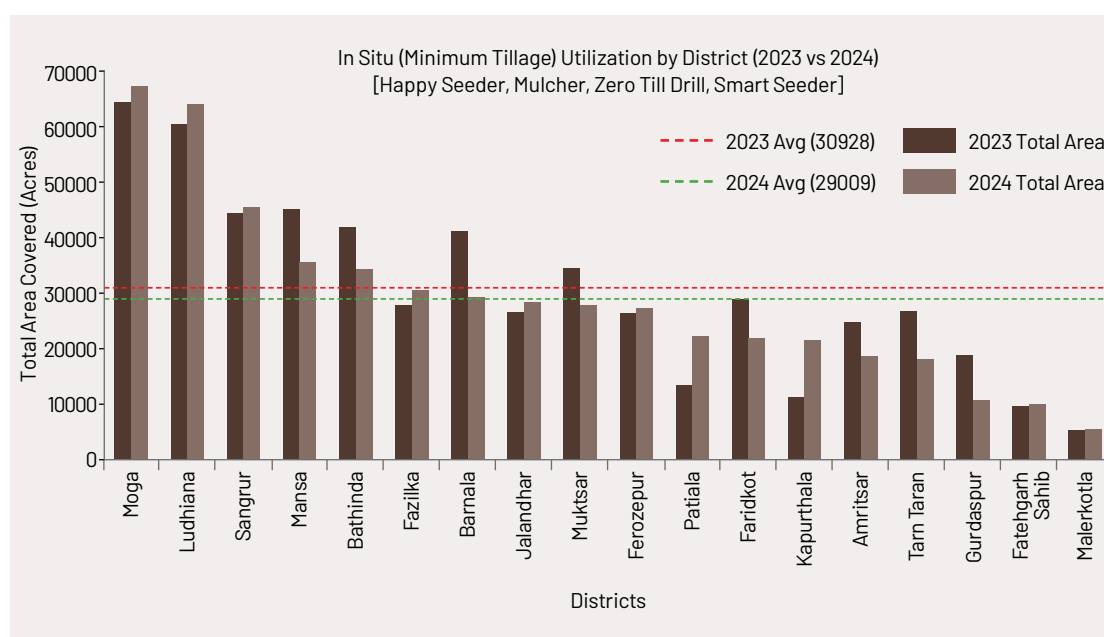
Mulching is a soil conservation practice in which crop residues—such as paddy straw from the previous harvest—are chopped and left on the soil surface rather than being removed or burnt. Using machines such as Mulchers, Happy Seeders, Smart Seeders, and Surface Seeders, the straw is shredded into smaller pieces and evenly spread to form a protective organic cover. This mulch layer helps regulate soil temperature, suppress weed growth and reduce moisture loss. Over time, the retained residue decomposes naturally, returning essential nutrients to the soil and significantly reducing irrigation requirements, thereby supporting sustainable and resource-efficient farming.







**Figure 7: Average operational area covered by minimum tillage machinery in 2023 and 2024**



## Zero-Till Drill: Dominant but gradually plateauing technology

- Trends in Zero-Till Drill utilization:** The Zero-Till Drill remains the most widely adopted implement for minimum tillage, reflecting farmers' continued reliance on established, cost-effective technologies for conservation agriculture. Its key advantage lies in its lower horsepower requirement compared to Happy Seeders or Smart Seeders, making it affordable and accessible to a broader base of small and marginal farmers. In 2024, the Zero-Till Drill covered 291,490 acres, exhibiting a marginal decline from 311,485 acres in 2023. This may be due to the fact that standard Zero-Till Drills often struggle in fields with heavy, loose paddy residue. The slight contraction likely reflects a gradual shift by some farmers toward more advanced machinery—such as Smart Seeders or ex situ residue management methods—which are designed to handle high residue volumes without clogging.





- **High-utilization zones:** The highest concentration of Zero-Till Drill usage is observed in the southern and southwestern districts, where soil texture and residue conditions are particularly well-suited to the implement. Mansa leads state-wide adoption (30,122 acres), closely followed by Sangrur (28,730 acres) and Fazilka (28,331 acres). These districts are characterized by lighter soils—ranging from sandy to sandy-loam. The Zero-Till Drill performs exceptionally well in lighter soils with manageable surface residue. In such agro-ecological conditions, the implement delivers optimal performance without requiring additional residue-clearing mechanisms, reinforcing its status as the most practical and economical conservation agriculture option in these districts.
- **Low-utilization zones:** Zero-Till Drill adoption remains limited in districts such as Malerkotla (1,408 acres) and Kapurthala (3,082 acres), where farming systems favour alternative in-situ residue management strategies. Kapurthala, located in the Doaba region, is a major center for potato, maize and vegetable cultivation, while Malerkotla (Malwa region) also has a significant focus on vegetable crops. Vegetable crops require a finely prepared, well-tilled seedbed to support proper root development. Zero-tillage is not suitable for this type of horticulture, driving farmers to rely on heavy tillage implements such as rotavators and Super Seeders. Consequently, the low footprint of Zero-Till Drills in these districts reflects field-level constraints rather than a lack of awareness or access.

## Happy Seeder: Second ranked but declining

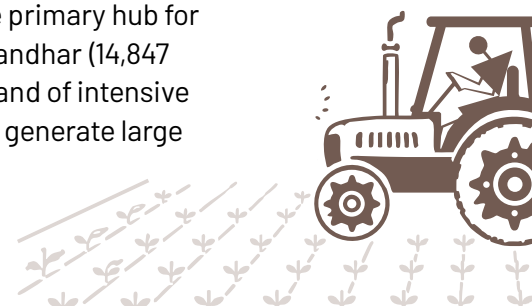
- **Trends in Happy Seeder utilization:** The Happy Seeder ranks as the second-most utilized minimum tillage implement; however, its operational area declined notably in 2024, decreasing from 156,925 acres in 2023 to 136,841 acres in 2024. This reduction appears to be driven by two key factors. First, agronomic challenges have been reported by farmers, including poor seed germination and increased pest incidence (such as pink stem borer and armyworm) when wheat is sown into heavy or poorly managed surface mulch. Second, technology substitution is likely underway, with farmers increasingly shifting toward newer and more efficient implements—such as the Smart Seeder and Super Seeder—which offer improved soil-seed contact and fewer operational constraints, particularly by enabling partial or full residue incorporation.



- **High-utilization zones:** Moga emerges as the epicenter of Happy Seeder operations, recording an exceptional 31,218 acres, followed by Ludhiana (22,405 acres) and Sangrur (13,436 acres), which also maintain highly active deployment networks. Ludhiana's prominence can be partly explained by the presence of Punjab Agricultural University (PAU), which historically led the Happy Seeder's development and large-scale promotional efforts. As a result, surrounding districts such as Moga and Sangrur also became early adopters. This long-standing association with the Happy Seeder, combined with farmers' strong perception of its operational advantages and reliable field performance, likely underpins the large acreage covered in these districts.
- **Low-utilization zones:** Happy Seeder adoption remains particularly low in the western districts of Muktsar (1,316 acres) and Fazilka (1,496 acres), both of which lie deep within Punjab's southwestern cotton belt. The Happy Seeder was specifically designed to address the challenge of dense, heavy paddy residue—particularly from long-duration parmal rice. However, cropping systems in these districts are dominated by cotton, kinnow (citrus) and shorter-duration or basmati rice varieties, which do not generate the large volumes of tough surface residue that necessitate the use of a Happy Seeder. Consequently, operating a heavy and fuel intensive Happy Seeder in these contexts is both agronomically and economically unnecessary, as standard Zero Till Drills perform well in these conditions.

## Mulcher: Dominance in the central belt

- **Trends in mulcher utilization:** Utilization of the mulcher ranks third. Mulching operations exhibited a positive trend, increasing from 84,425 acres in 2023 to 88,713 acres in 2024, and reflecting a growing regional shift toward targeted residue sizing and management. This positive trajectory suggests farmers are increasingly adopting a "two-pass" strategy: using a mulcher first to chop the residue, followed by using a Zero-Till Drill or Spatial Drill for sowing. Chopped residue decomposes more rapidly, improves soil organic carbon and significantly reduces weed emergence, factors that are collectively driving its growing popularity.
- **High-utilization zones:** The central districts exhibit a clear preference for mulching over other minimum tillage interventions. Ludhiana emerges as the primary hub for mulching with 27,329 acres, followed by substantial adoption in Jalandhar (14,847 acres) and Kapurthala (11,743 acres). These districts form the heartland of intensive paddy cultivation, where long-duration, high-yielding rice varieties generate large





volumes of dense and thick stubble. Under such extreme biomass loads, Happy Seeders often experience operational challenges, including frequent clogging, making mulchers essential for effectively chopping and shredding residues prior to sowing. Additionally, Jalandhar and Kapurthala – in the Doaba region- along with large parts of Ludhiana are major hubs for potato and vegetable cultivation following the paddy harvest. In these systems, chopped and mulched residue decomposes more rapidly, improving the soil tilth and organic matter. This creates a more favorable seedbed for root and vegetable crops compared to leaving long stubble on the surface, further reinforcing the dominance of mulchers in the central belt.

- **Low-utilization zones:** Mulching operations are almost absent in certain southern and northern pockets, most notably in Mansa (319 acres) and Gurdaspur (347 acres). Gurdaspur, located in the Majha region, is well known for the production of high-quality basmati rice. Unlike long-duration parma rice, basmati straw is highly valued as dry fodder for cattle and is therefore commonly collected through manual harvesting or mechanical baling. As a result, very little surface residue remains in the field to warrant mulching operations. Similarly, in Mansa, located in the southwest, farmers typically grow cotton and lighter paddy varieties which do not generate the large volumes of dense biomass needed to justify the use of a dedicated residue-shredding pass. Consequently, for farmers in these areas, operating a standalone mulcher represents an unjustifiable additional cost in terms of fuel consumption, labor and time, explaining the persistently low levels of mulcher adoption.

## Smart Seeder: Emerging technology

- **Trends in Smart Seeder utilization:** Although it represents the smallest total acreage (5,119 acres in 2024) among minimum tillage technologies, the Smart Seeder is demonstrating rapid proportional growth compared to its 2023 utilization (3,875 acres), indicating early stages of technology diffusion.

### Three main factors of the growing adoption of the smart seeder



**Addressing prior technological limitations:** The Smart Seeder represents an intermediate technology, between surface-residue seeding and full incorporation systems. By partially incorporating residues while placing seed into a clean soil slit, it mitigates residue interference and substantially improves germination outcomes compared to traditional Happy Seeders.



**Operational efficiency:** The Smart Seeder is generally lighter and requires lower tractor horsepower than heavy incorporation machinery, translating into reduced fuel consumption and operating costs while maintaining high field capacity and productivity.



**Early-adopter momentum:** The observed rapid growth suggests that early adopters are experiencing positive field performance and disseminating favorable feedback within their local farming networks.

- **High-utilization zones:** The adoption of the Smart Seeder is currently concentrated in a small set of districts, notably Fatehgarh Sahib (950 acres), Barnala (852 acres) and Sangrur (691 acres). Districts such as Fatehgarh Sahib and Barnala are characterized by highly active farmer cooperatives and progressive farming communities with a comparatively high-risk appetite for experimenting with new technologies. Given that the Smart Seeder is an emerging technology designed to address the shortcomings of older machinery—particularly germination issues associated with the Happy Seeder—state agricultural departments and Krishi Vigyan Kendras (KVKs) have strategically targeted these well organized districts for initial pilot programs.
- **Low-utilization zones:** Adoption of the Smart Seeder remains limited in Muktsar (67 acres) and Malerkotla (80 acres). The Smart Seeder is designed to manage heavy paddy residue more effectively than the Happy Seeder. However, Muktsar does not typically experience the extreme residue loads that would necessitate such an advanced intervention and, consequently, its use remains limited in the district. In Malerkotla, Punjab's newest district, institutional factors likely play a more prominent role. The early diffusion of emerging technologies such as the Smart Seeder depends heavily on targeted government subsidies, Krishi Vigyan Kendra (KVK) demonstrations and allocations through CHCs. As a recently established administrative unit, Malerkotla may currently lie at the tail end of the initial supply chain and promotional rollout for this specific machine, contributing to its low observed utilization.

### 3.4.3. In situ crop residue management: incorporation

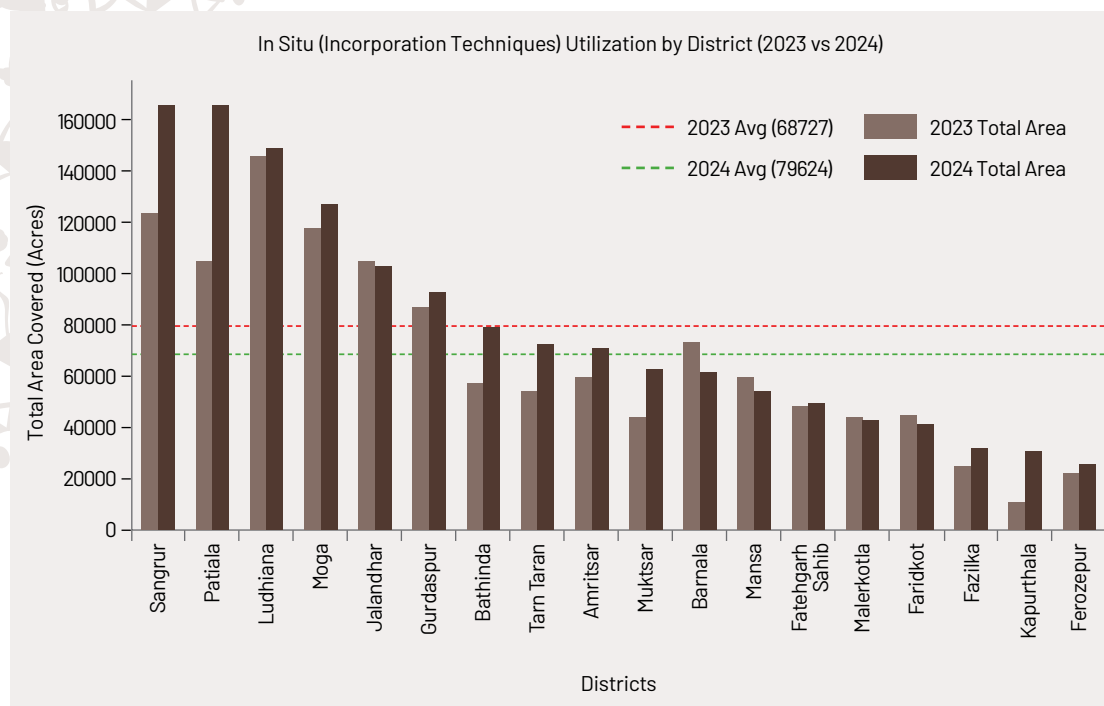
Incorporation is a soil management technique in which crop residues –such as paddy straw are physically mixed into the soil rather than being left on the surface. Unlike mulching, which typically involves only surface chopping or shredding of the straw, incorporation requires substantially higher energy inputs and the use of heavy-duty machinery such as the Super Seeder, rotavator, or mould-board (MB) plough to cut through, invert and mix the soil. This energy-intensive process buries residues within the soil, accelerating their natural decomposition and integrating them into the soil structure. The average district area managed through incorporation increased from 67,815 acres in 2023 to 70,704 acres in 2024, indicating a steady and systemic growth.

**Figure 8: Transition from raw crop stubble (before) to incorporated mulch (after) to prevent residue burning and enhance soil health**





**Figure 9: Average operational area covered under incorporation-based techniques in 2023 and 2024**



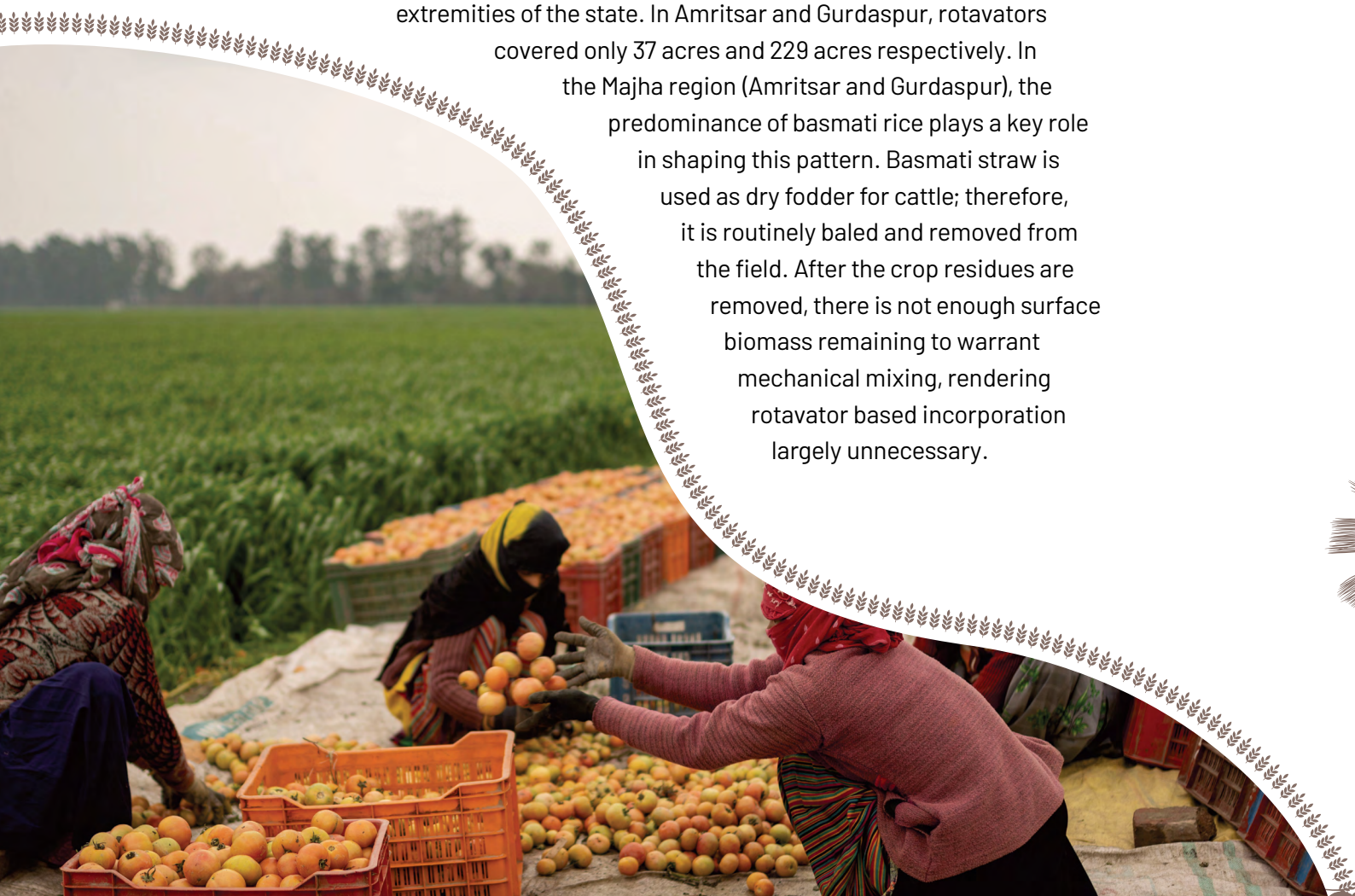
## Super Seeder

- Trends in Super Seeder utilization:** The Super Seeder has consolidated its position as the state's leading residue-management implement. Its utilization expanded from 785,640 acres in 2023 to 888,506 acres in 2024. The machine represents a major advance for Punjab's farmers by integrating residue-chopping, soil-mixing, seeding, and soil-pressing into a single pass, thereby significantly reducing fuel consumption and labor requirements. From an agronomic perspective, it is favored for its ability to manage heavy paddy stubble without the clogging issues associated with older drills, while simultaneously leaving behind a uniformly tilled field that reduces habitats for rodents and other pests.
- High-utilization zones:** Districts characterized by heavier soils exhibit the strongest reliance on the Super Seeder. Sangrur leads adoption with 117,560 acres, followed by Gurdaspur (90,037 acres) and Bathinda (75,949 acres). These districts predominantly cultivate long duration rice varieties that generate large volumes of dense and resilient stubble. Under such conditions, the Super Seeder's substantial weight and high power are well suited for effectively cutting through and incorporating this biomass. In addition, these relatively affluent agricultural belts are well endowed with high horsepower tractors (typically 55–65 HP and above), enabling farmers to operate such heavy duty machinery with ease.

- **Low-utilization zones:** Utilization is substantially lower in the western and border districts such as Ferozepur (15,512 acres) and Fazilka (19,930 acres). These areas are characterized by lighter, sandy loam soils, where the aggressive and heavy operating action of the Super Seeder is often unnecessary and may even be detrimental to soil structure when compared with lighter seeding and residue management implements.

## Rotavator: The multipurpose standard

- **Trends in rotavator utilization:** Rotavators continue to maintain a substantial operational footprint, although usage declined marginally from 253,231 acres in 2023 to 246,584 acres in 2024. Beyond wheat cultivation, rotavators remain the standard implement for preparing fine seedbeds for potato and pea cultivation in districts undergoing crop diversification. They function as the “workhorse” of CHCs, frequently deployed in combination with mulchers when Super Seeders are unavailable.
- **High-utilization zones:** Rotavator usage is concentrated in the central districts, where rapid residue mixing is required. Ludhiana leads the state with 77,272 acres, followed by Jalandhar (47,650 acres) and Patiala (40,386 acres). These districts are major hubs for potato and vegetable cultivation, cropping systems that demand a finely pulverized seedbed. Rotavators align well with these production requirements by rapidly incorporating residues and creating suitable soil tilth in a single or limited number of passes, enabling timely field preparation immediately after paddy harvest.
- **Low-utilization zones:** Rotavator usage is minimal in the northern and southern extremities of the state. In Amritsar and Gurdaspur, rotavators covered only 37 acres and 229 acres respectively. In the Majha region (Amritsar and Gurdaspur), the predominance of basmati rice plays a key role in shaping this pattern. Basmati straw is used as dry fodder for cattle; therefore, it is routinely baled and removed from the field. After the crop residues are removed, there is not enough surface biomass remaining to warrant mechanical mixing, rendering rotavator based incorporation largely unnecessary.





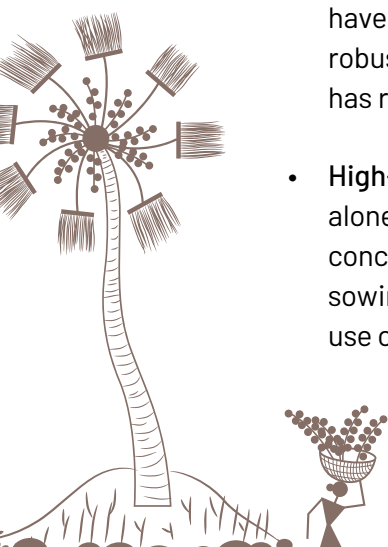
## Mould-board plough: Specialized deep tillage

- **Trends in mould-board utilization:** The mould-board (MB) plough recorded largely stable usage, covering 72,240 acres in 2024, compared to 79,275 acres in 2023. As a deep-tillage implement, it plays a critical role in breaking the subsurface “hardpan” formed through repeated paddy puddling over multiple seasons. However, because deep tillage with an MB plough is agronomically recommended only once every three to four years, its overall footprint remains relatively steady and considerably smaller than that of annually used sowing or residue management implements.
- **High-utilization zones:** MB ploughs are concentrated in the central corridor of the state, with Ludhiana (20,330 acres) and Jalandhar (12,318 acres) emerging as the primary adopters. This spatial pattern reflects the influence of Punjab Agricultural University (PAU), which has consistently promoted periodic soil inversion as a corrective intervention to alleviate compaction, improve water infiltration and bury weed seeds.
- **Low-utilization zones:** MB plough usage remains limited in the northern and southern ends of the state. In Amritsar, for instance, MB ploughs were used on just 205 acres, indicating very limited adoption. In the southern cotton belt, particularly districts such as Mansa, lighter soil textures do not typically develop severe subsurface hardpans. As a result, the agronomic justification for deep soil inversion is limited. In this context, the relatively high fuel and operating costs of MB ploughing make it an uneconomical option for most farmers, explaining its very limited use in the region.



## Roto Drill: Technology in transition

- **Trends in Roto Drill utilization:** Roto Drill utilization declined from 57,100 acres in 2023 to 46,202 acres in 2024. While the Roto Drill initially served as a transitional solution by combining tillage and sowing in a single operation, it performs poorly under conditions of heavy, standing paddy residue. As residue loads have increased and field conditions have become more demanding, farmers have increasingly shifted toward the more robust Super Seeder, which offers superior residue handling capacity. This transition has resulted in the gradual phasing out of the Roto Drill as a preferred option.
- **High-utilization zones:** Utilization remains highly localized in pockets, with Sangrur alone accounting for nearly 43% of the state’s total usage (19,629 acres). This concentration reflects the district’s history as an early adopter of combined tillage and sowing machinery, where familiarity with single pass systems has sustained residual use of the Roto Drill despite broader technological shifts.



## Disc plough: Accelerated decline

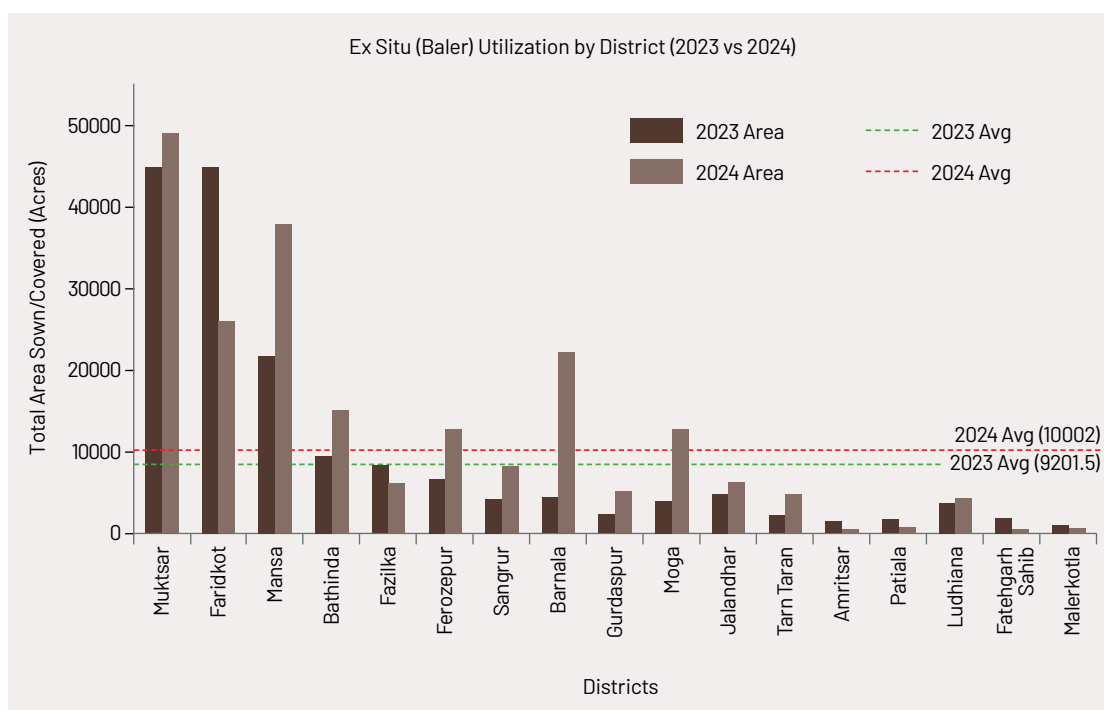
- **Trends in disc plough utilization:** The disc plough is the fastest-declining implement, with utilization falling sharply from 45,420 acres in 2023 to just 19,130 acres in 2024. Although disc ploughs are well suited to hard, dry soil conditions, they perform poorly in wet paddy fields, where they are ineffective at mixing wet paddy straw. In addition, their draft-intensive design demands tractors with high pulling power, increasing fuel consumption and operational costs. As a result, farmers are increasingly phasing out disc ploughs in favor of power take-off or PTO driven implements such as rotavators, which deliver more effective residue mixing and soil preparation in fewer passes.
- **High-utilization zones:** Usage has become increasingly localized, concentrated in a few specific districts—most notably Fatehgarh Sahib (8,377 acres) and Moga (6,506 acres). This limited adoption likely reflects niche applications, such as land reclamation or the management of exceptionally hard or compacted soil conditions, where the disc plough's cutting action remains advantageous despite its broader decline.

### 3.4.4. Ex situ crop residue management machinery

#### Baler machine

A baler machine is an agricultural implement that compresses crop residues—such as hay, straw or stubble—into compact, transportable bales. It is typically tractor-mounted and used in the field to facilitate collection, storage and transport.

**Figure 10: Average operational area covered by balers in 2023 and 2024**





- **Trends in baler utilization:** The average area covered per district rose from 9,201 acres in 2023 to 10,002 acres in 2024, representing an 8.7% increase. This upward trend indicates a steady expansion in baling infrastructure and capacity, alongside a broader operational shift toward the removal of crop residues from fields for off field or external applications.
- **High-utilization zones:** Muktsar, Mansa and Faridkot consistently recorded baling activity well above the state average in both years, firmly establishing themselves as core hubs. While Bathinda was only marginally above the state average in 2023, its pronounced growth in 2024 consolidated its position within this group. This sustained dominance indicates the presence of mature and well integrated baled biomass supply chains in these districts, likely supported by strong localized demand and/or proximity to downstream consumption facilities such as biopower plants or compressed biogas (CBG) facilities.

Sangrur and Gurdaspur have also emerged as key growth areas. Both districts operated well below the state average in 2023 but expanded baling coverage by 100% or more within a single year. Sangrur, in particular, increased from 4,140 acres to 8,281 acres, rapidly narrowing the gap with the state average. This sharp expansion points to successful machinery deployment and indicates a fast tracked transition in regional residue-management practices.

Despite overall growth in baling activity, the data reveal a pronounced spatial concentration in the southwestern belt. In 2024, the top three districts—Muktsar, Mansa and Faridkot—accounted for approximately 67% of the total area covered across all 17 districts. In these leading districts, baling operations have scaled to levels where strategic attention must increasingly shift toward downstream constraints, particularly logistics, storage and market linkages.

- **Low-utilization zones:** Out of 17 districts, 12 remain below or well below the state average (as indicated by the horizontal reference line), underscoring that adoption of ex situ residue management remains highly localized rather than broadly or uniformly distributed. Districts such as Amritsar or Ferozepur—which recorded declines despite the statewide upward trend—likely continue to face structural barriers, including high operational costs, limited availability of local off takers and a stronger preference for in situ residue management approaches such as mulching or incorporation.





## 04. Conclusion

The 2023–2024 machinery mapping exercise conducted under the PRANA project provides critical insights into the state of agricultural mechanization across Punjab. It also provides valuable insights about the adoption, preferences and performance of Crop-Residue Management (CRM) machinery. By tracking machine availability, ownership patterns, subsidy utilization and operational coverage, this report offers a data-driven foundation for shaping more effective agricultural policies and targeted field interventions to increase the adoption of CRM machinery.

Government subsidies have played a central role in supporting the adoption of CRM machinery such as the Super Seeder and Happy Seeder. In contrast, conventional equipment, including rotavators and standard combine harvesters, has largely been acquired through private investment, reflecting the entrenched nature of these technologies within the region's farming systems. This contrast between subsidy enabled uptake of newer CRM technologies and the prevalence of privately financed conventional machinery highlights an important dynamic that should be carefully considered in the design of future agricultural mechanization programs.

One of the report's most significant findings is a clear shift toward individual ownership of agricultural machinery. As





farmers increasingly invest in personal ownership of CRM equipment rather than relying on shared Custom Hiring Centers or cooperative societies, access to machinery during the critical 15–20-day sowing window has become more reliable. However, this transition also places greater responsibility on individual farmers for the upkeep and repair of CRM machinery. This shift highlights the growing importance of expanding localized, authorized service and maintenance infrastructure to ensure the long term functionality and cost effectiveness of privately owned equipment.

The prominence of the Super Seeder as a widely used in situ residue management tool can be attributed to its operational efficiency, as its single-pass functionality reduces time, fuel consumption, and labor requirements. At the same time, the declining use of the Happy Seeder and the gradual uptake of the Smart Seeder suggest an evolving technological landscape, shaped in part by field-level agronomic considerations such as germination quality and pest management. Taken together, these patterns highlight the importance of aligning future subsidy allocations with next-generation implements that better address observed field level challenges.

Spatial analysis further indicates that machinery adoption patterns are not uniform across Punjab. Factors such as soil type, cropping patterns and proximity to biomass off-take facilities influence both the type of machinery adopted and the intensity of its use. As a result, a uniform subsidy policy fails to account for these regional differences. Heavy-residue-incorporation machinery is better suited to the high-residue districts of the central belt, whereas lighter conservation drills are more appropriate for the sandy soils of the south-western region. Similarly, while baler adoption is increasing, its economic viability remains closely tied to the presence of established biomass supply chains and nearby industrial consumers.

In conclusion, available evidence indicates a substantial reduction in reported crop-residue burning incidents in Punjab between 2021 and 2025, pointing to meaningful progress in addressing a long standing environmental challenge. Maintaining this trajectory, however, will likely depend on continued refinement of policy instruments, with attention to context, rather than reliance on uniform approaches. Greater sensitivity to regional soil conditions and cropping systems, attention to institutional capacity for maintenance and service delivery, and sustained evaluation of machinery performance under varying field conditions may all be important in shaping future interventions. While the findings of this report do not prescribe specific solutions, they provide an empirical basis that can inform ongoing policy deliberations and support more context responsive strategies for advancing sustainable residue management in the state.



## 05. Recommendations

### 5.1. Implement agro-ecological and soil-specific subsidy zoning and awareness measures

A uniform, state-wide subsidy framework risks creating mismatches between machinery design and local agro-ecological conditions. Future mechanization policies would benefit from explicitly aligning subsidized CRM equipment with region-specific soil characteristics and dominant cropping systems. This zoning approach should be complemented by targeted awareness and extension efforts to help farmers understand soil specific machinery suitability.

- **Restrict heavy machinery in lighter soil:** The use of heavy machinery, such as the Super Seeder, should be restricted in lighter soil types. The Super Seeder is a heavy implement designed to aggressively incorporate thick crop residue in clay loam soils. In the southwestern belt (e.g., Fazilka and Ferozepur), where soils are predominantly lighter and sandy loam, the use of such heavy machinery can unnecessarily disrupt soil structure, increase compaction and reduce long term soil health. Subsidies for Super Seeders should therefore be restricted or gradually phased out in these specific agro ecological zones.
- **Prioritize Zero-Till in suitable zones:** The Zero-Till Drill has proven to be both technically effective and significantly more cost-efficient in lighter, sandy-loam soils. Policy frameworks should therefore prioritize subsidies for Zero-Till and Smart Seeders in the southwestern belt to promote minimum-tillage practices, reduce soil disturbance and support long-term conservation agriculture outcomes.
- **Guidance on rotational deep tillage:** Continuous puddling under paddy cultivation creates the formation of compacted subsurface hardpans. Agronomic policy should explicitly promote rotational tillage rather than continuous heavy tillage. Extension services should incentivize the use of mould-board (MB) ploughs strictly on a 3–4-year rotational basis to break hardpans, improve water infiltration and restore soil structure, while discouraging routine deep tillage.





## 5.2. Prioritize “Right-to-Repair” infrastructure over capital acquisition

While the initial phase of the CRM scheme was successful in accelerating machine adoption, the policy should now evolve to address the full lifecycle of these assets.

- **Fund localized service networks:** With the large influx of machines from the 2018–2021 subsidy boom now reaching a stage that requires significant technical overhauls—particularly engine and gearbox repairs—there is an urgent need for strengthened maintenance support. Policy must shift to subsidizing or authorizing local service centres, rather than focusing solely in funding new equipment purchases.
- **Incentivize preventive maintenance:** Machinery owned by institutions such as cooperatives and CHCs tends to deteriorate faster than individually owned assets due to limited access to immediate repair funds and diffused “collective responsibility.” Introducing maintenance-linked incentives—such as maintenance vouchers or tax benefits—for CHCs that demonstrate regular preventive servicing could significantly extend asset life and safeguard public investment.



### 5.3. Strengthen enforcement of harvest-stage chopping (Super SMS retrofits)

The data suggests that the existing harvesting system may be approaching its operational limits. While the voluntary adoption of integrated residue management technologies has remained insufficient.

- **Enforce mandatory retrofitting:** While standard combine harvesters remain in widespread use, the absence of Super SMS attachments often results in the formation of dense straw windrows. Such accumulation can hinder the efficacy of no-till seeding equipment and, in certain cases, create a logistical incentive for residue burning to clear fields. Addressing this gap requires stronger enforcement of existing mandates that require all operational combine harvesters to be fitted with functional Super SMS attachments. By complementing enforcement with mandatory retrofitting programs and rigorous field-level performance verification, crop residue can be effectively managed at the point of harvest, supporting both farmers' operational needs and regional conservation goals.
- **Redirect subsidies towards retrofits:** To mitigate the financial burden of this mandate, subsidy support should be redirected towards retrofit kits for existing combines. This approach would ensure residue is effectively chopped during harvesting, addressing the problem at its source rather than relying on post harvest interventions.

### 5.4. Synchronize ex situ subsidies with industrial market mapping

Deploying ex situ residue management machinery, particularly balers, in districts without viable downstream markets is economically unsustainable and has constrained adoption.

- **Link deployment to off-taker infrastructure:** The financial viability of balers is critically dependent on the presence of downstream buyers such as biomass power





plants or compressed biogas (CBG) facilities. In districts lacking such infrastructure, high transportation costs erode returns and render baler operations unviable. Subsidy allocation for balers should therefore be dynamically aligned with the presence—or confirmed development—of local industrial off-takers.



- **Incentivize decentralized off-takers:** In underperforming districts, the constraint is not machine availability but the absence of reliable, year round end use markets for paddy straw. This gap cannot be addressed through CRM subsidies alone. Targeted industrial interventions—such as capital grants or tax incentives—should support decentralized bio energy plants, CBG units or straw based industrial boilers that can provide consistent, price linked demand and anchor baler operations locally.

## 5.5. Tailor policies for crop-diversification pathways

The agricultural policy must support the distinct agronomic requirements of farmers transitioning away from the rice-wheat rotation towards horticulture and diversified cropping systems.

- **Recognize the agronomic limits of Zero-Till in diversified cropping:** In districts such as Jalandhar and Kapurthala—major hubs for potatoes, maize and winter vegetables—Zero-Till systems are often agronomically unsuitable. These crops require a finely pulverized, level seedbed for optimal establishment. A uniform push toward Zero-Till risks undermining diversification outcomes in such regions.
- **Design subsidies for two-pass residue management and seedbed preparation:** For diversified and horticultural systems, finely shredded and incorporated residue decomposes more rapidly, improving soil organic matter, tilth and moisture retention—critical for root and vegetable crops. Subsidy frameworks should therefore include dedicated tiers for two-pass machinery combinations (e.g., a chopper/mulcher followed by a rotavator), explicitly targeted at farmers adopting crop-diversification pathways.







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