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### Sustainable crop residue management in paddy-wheat system: Government initiatives and KVK interventions

<sup>1</sup>Meenakshi Sangwan, <sup>2</sup>Kuldeep Singh, <sup>3</sup>Sukirtee, <sup>4</sup>Meena Siwach, <sup>5</sup>Mohammad Ahatsham and <sup>6</sup>Rupender Kumar

<sup>1</sup>District Extension Specialist, (Agronomy), CCSHAU Krishi Vigyan Kendra, Rohtak, Haryana, India

<sup>2</sup>Senior District Extension Specialist, (Agricultural Engineering), CCSHAU Krishi Vigyan Kendra, Sonipat, Haryana, India

<sup>3</sup>DES, (Soil Science), CCSHAU Krishi Vigyan Kendra, Rohtak, Haryana, India

<sup>4</sup>Director/Sr. Coordinator, Krishi Vigyan Kendra, Rohtak, Haryana, India

<sup>5</sup>SMS, (Agrometeorology), CCSHAU Krishi Vigyan Kendra, Rohtak, Haryana, India

<sup>6</sup>DES, (Agricultural Extension), CCSHAU Krishi Vigyan Kendra, Rohtak, Haryana, India

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Corresponding Author: Dr. Meenakshi Sangwan

#### Abstract

Crop residue management (CRM) has emerged as one of the most pressing challenges in the paddy-wheat cropping system of North-West India. Residue burning contributes to severe air pollution, soil degradation, greenhouse gas emissions, and health hazards. In response, government initiatives under the CRM scheme (2018 onwards) have been supplemented by field-level extension interventions of Krishi Vigyan Kendras to promote in-situ residue management technologies, IEC campaigns, and CHCs. This paper examines the case of Rohtak district, Haryana, as a representative site for assessing CRM adoption. Using secondary datasets (2018-2025) on paddy area, production, productivity, burning incidences and CHC establishment, and primary data from KVK Rohtak records on IEC activities, and field demonstrations, the study analyses the effectiveness of interventions. Results indicate that although the area under paddy in Rohtak increased from 48,000 ha in 2018-19 to 84,500 ha in 2024-25, stubble burning incidents sharply declined from 53 to 14 over the same period. Concurrently, the number of burning-free villages rose from 95 to 125. More than 20 CRM machines were purchased and over 17,000 farmers participated in awareness campaigns. The study concludes that CRM interventions in Rohtak significantly curtailed burning, enhanced soil health, and promoted sustainable farming.

**Keywords:** Crop residue management, awareness programs, burning free villages, machinery demonstrations, economics

#### Introduction

The Indo-Gangetic Plains (IGP) of India form the backbone of the nation's food security system, contributing nearly 75% of rice and wheat to the central food grain pool. India generates around 500 million tons (MT) of crop residues annually, significantly higher than other countries in the region (Meena *et al.*, 2022) <sup>[7]</sup>. In India, around 141 MT of surplus crop residue is generated, of which 92 MT is burned (NPMCR, 2023) <sup>[9]</sup>. The major crop residue responsible for burning is rice (43%), followed by wheat (21%), sugarcane (19%), and the oilseed crop (5%), (Bhuvaneshwari *et al.*, 2019) <sup>[1]</sup>. Similarly, the total amount of crop residue generated from cereal crops in Haryana state is 27.83 MT, of which surplus residue (9.08 MT) is burnt annually (NPMCR, 2017) <sup>[10]</sup>. The paddy-wheat rotation dominates Haryana, Punjab, and western Uttar Pradesh. However, the mechanized harvesting of paddy leaves behind 6-8 tonnes of straw per hectare, most of which farmers traditionally dispose of through open-field burning. Approximately 23 million tonnes of paddy residue are burned in Punjab, Haryana, and Uttar Pradesh, leading to severe regional pollution (Ravindra *et al.*, 2019; Singh, 2018; IARI, 2020)

[11, 13, 5]. The burning of one tonne of paddy straw releases 3 kg particulate matter, 60 kg CO, 1460 kg CO<sub>2</sub>, 199 kg ash and 2 kg SO<sub>2</sub> (DAC&FW, 2024) <sup>[4]</sup>. This practice leads to the emission of greenhouse gases (GHGs), particulate matter (PM<sub>2.5</sub>, PM<sub>10</sub>), and toxic gases, exacerbating climate change and human health degradation (Sarkar, 2018) <sup>[13]</sup>. Burning crop residues irrespective of their composition has a negative effect on the microbial population, organic matter content, micro and macronutrients, content of soil, in a nutshell deteriorates overall soil health (Raza *et al.*, 2019 and Jia *et al.*, 2024) <sup>[12]</sup>. Open burning also increases dependency on chemical fertilizers.

Recognizing the severity of the problem, the government of India launched a central sector scheme on "Promotion of Agricultural Mechanization for In-situ Management of Crop Residue Management" in 2018. Rice residues can be managed using in-situ (retention of rice straw on the surface as mulch on surface or incorporation of the residue into the soil by mixing or inverting) or ex-situ (use of paddy straw for energy, mulching, biochar, etc.) straw management technologies. Among the different options for managing

paddy straw, in-situ utilization stands out as the most practical, cost-effective, and environmentally sustainable approach (Singh *et al.*, 2020) <sup>[17]</sup>. Under this scheme, subsidies on machinery such as happy seeder, zero-till seed-cum-fertilizer drill, mulchers, super seeder, rotary slasher, mulcher, chopper etc. were provided to farmers and Custom Hiring Centres (CHCs). State governments, KVKs, and agricultural universities were made responsible for IEC campaigns, demonstrations, and farmer training. KVKs are frontline extension institutions that operationalize policies at the grassroots level. In Rohtak, KVK played a central role by conducting awareness programmes, field demonstrations, school and college sensitization campaigns, and farmer trainings. The present study was conducted to analyze trends in paddy area, production, productivity, and residue burning in Rohtak district, to assess the role of IEC activities, CRM machinery distribution, and CHCs in reducing burning and to evaluate the sustainability and replicability of CRM interventions.

### Methodology

The research was carried out across various blocks of Rohtak district in Haryana, situated in the north-western Indo-Gangetic Plains. The region is marked by a semi-arid climate, soils ranging from sandy loam to clay loam, and the dominance of the rice-wheat cropping system. Rohtak has been identified as a priority district under the Crop Residue Management (CRM) Scheme, and between 2018 and 2025, KVK Rohtak implemented multiple interventions under this programme. Seventeen villages were purposively selected from four major paddy-growing blocks of the district for intensive information, education and communication (IEC) activities, frontline demonstrations, and the establishment of Custom Hiring Centres. These villages included Sanghi, Bainsi, Titoli, Kharak Jatan, Rithal, Ajaib, Kahni, Baliyana, Gandhara, Dhamar, Chiri, Polangi, Nandal, Chamaria, Kansala, Humayunpur, and Madina. Primary information was gathered through farmer interviews, focus group discussions, and records maintained by KVK Rohtak, while secondary data on paddy area, production, and productivity were obtained from the Department of Agriculture and Farmers' Welfare, Rohtak, along with residue burning statistics from the CREAMS portal ([creams.iari.res.in](https://creams.iari.res.in)). Additionally, participatory insights were generated from farmer interactions during trainings and awareness programmes. The interventions by KVK encompassed a multi-pronged approach to promote sustainable crop residue management. IEC activities were conducted at various levels through village-level awareness programmes, block-level events, district-level campaigns, specialized trainings, school and college programmes, five-day farmer training courses, and field days to build knowledge and awareness among stakeholders. On-farm demonstrations of CRM technologies such as the happy seeder, super straw management system (SMS), super seeder, mulcher, slasher, and zero till drill were organized to showcase practical benefits and enhance farmer confidence. To ensure accessibility, particularly for small and marginal farmers, the State Agriculture Department established Custom Hiring Centres equipped with CRM machinery. Furthermore, continuous monitoring and evaluation were undertaken through machinery demonstrations on farmer fields,

assessment of adoption rates, and incorporation of farmer feedback to refine strategies and strengthen impact.

The collected data were systematically organized into tables and graphs to study patterns in paddy cultivation, residue burning, CRM machinery distribution and CHCs and the reach of IEC activities. A comparison with state-level figures was undertaken to assess Rohtak district's share and performance. In addition, an economic evaluation of various machinery demonstrations was carried out through comparative analysis to determine their cost-effectiveness and practical viability.

### Results

The large-scale adoption of crop residue management interventions in Rohtak district has resulted in significant improvements in residue utilization, reduction in stubble burning incidents, and overall sustainability of the paddy-wheat cropping system. The interventions included awareness programs, capacity building, demonstrations, and mechanization support facilitated by KVK Rohtak.

Analysis of secondary data reveals a fluctuating but significant trend in paddy area, production, and productivity in Rohtak district over the past decade. The interventions under CRM contributed to stabilizing yields despite climate variability and resource constraints. After 2018, the productivity or yield per hectare did not change much over time, but both cultivated area and overall production increased significantly. The steady increase in area and production of paddy crops no doubt solved the problem of food and nutritional security of the country by contributing large amounts of food grain to the central pool from a relatively small area of the state. Simultaneously, the amount of paddy stubbles increased, which may lead to more stubble burning. But, this increase in area and production aligns with the period when CRM demonstrations and awareness efforts were strengthened, showing that residue management practices played a key role in improving soil condition and making better use of inputs.

### Area, production share and paddy straw burning incidence in Rohtak with respect to Haryana state

The trend of paddy area in Rohtak district compared with the overall Haryana state. Rohtak contributed between 3.32% (2018-19) and 5.00% (2023-24) of Haryana's total paddy area (Table 1). A steady rise in cultivated area was recorded, increasing from 48,000 ha in 2018-19 to 84,500 ha in 2024-25, showing a 76% increase. This table also represents the trend of paddy straw burning incidents. Despite the expansion in area under paddy cultivation, Rohtak has shown substantial reduction of paddy straw burning incidents from 53 incidents in 2018-19 to just 14 incidents in 2024-25. This indicates the impact of CRM interventions and government initiatives. In Haryana overall, burning events decreased drastically from 9,225 in 2018-19 to 1,055 in 2024-25. Rohtak's share fluctuated between 0.19% and 1.3%, showing that the district's efforts were in line with state-wide improvements and this reduction is due to large-scale adoption of in-situ management. The decline highlights the effectiveness of CRM interventions in balancing productivity with sustainability.

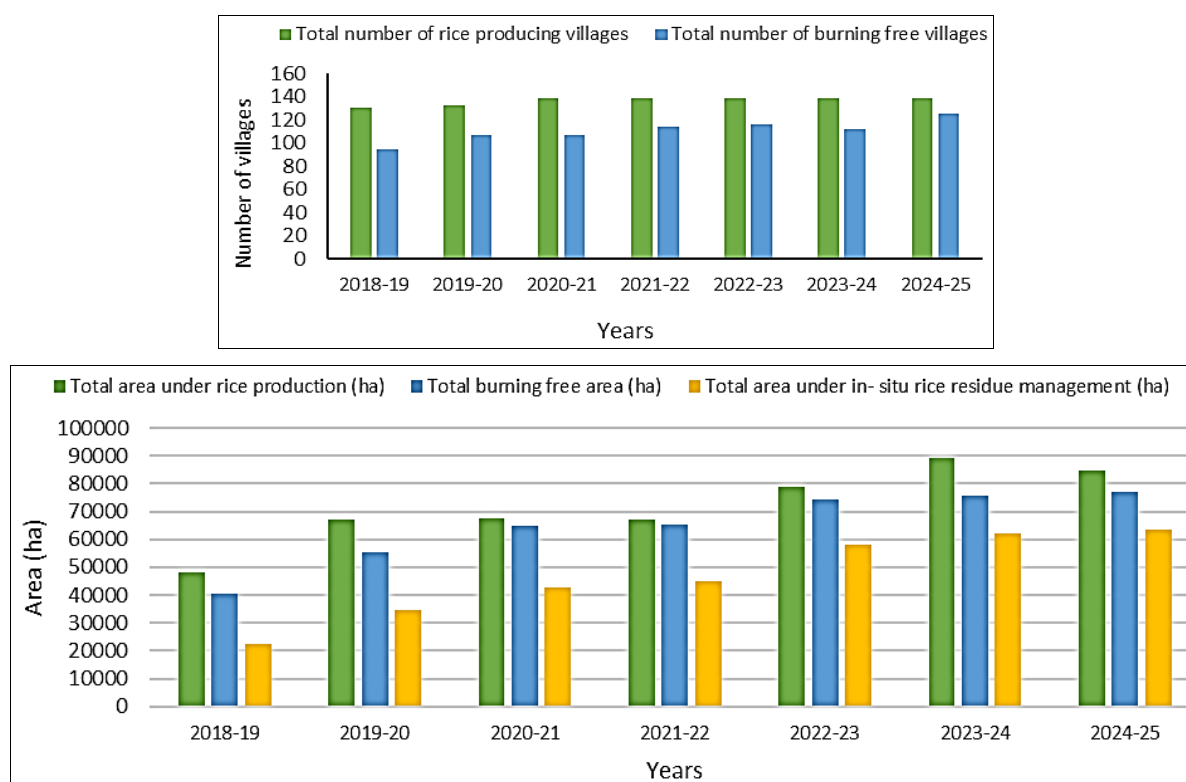
**Table 1:** Area, production share, and straw burning in Rohtak district (2018-19 to 2024-25)

| Year    | Area under paddy crop in District Rohtak (ha.) | Area under paddy crop in Haryana State (ha.) | Area of Paddy crop in District Rohtak in Comparison to Haryana State (%) | Number of Paddy straw burning incidence in District Rohtak | Number of Paddy straw burning incidence in Haryana State | Paddy Straw burning incidence in District Rohtak in comparison to Haryana State (%) |
|---------|------------------------------------------------|----------------------------------------------|--------------------------------------------------------------------------|------------------------------------------------------------|----------------------------------------------------------|-------------------------------------------------------------------------------------|
| 2018-19 | 48000                                          | 1446900                                      | 3.32                                                                     | 53                                                         | 9225                                                     | 0.57                                                                                |
| 2019-20 | 67000                                          | 1559000                                      | 4.30                                                                     | 23                                                         | 6364                                                     | 0.36                                                                                |
| 2020-21 | 67700                                          | 1525800                                      | 4.44                                                                     | 41                                                         | 3701                                                     | 1.1                                                                                 |
| 2021-22 | 67100                                          | 1534500                                      | 4.37                                                                     | 17                                                         | 5724                                                     | 0.29                                                                                |
| 2022-23 | 78710                                          | 1661280                                      | 4.73                                                                     | 28                                                         | 3149                                                     | 0.89                                                                                |
| 2023-24 | 89060                                          | 1777700                                      | 5.00                                                                     | 36                                                         | 1940                                                     | 0.19                                                                                |
| 2024-25 | 84500                                          | 1837070                                      | 4.60                                                                     | 14                                                         | 1055                                                     | 1.3                                                                                 |

### Enhanced CRM adoption leading to more burning-free area and villages

Alongside reduction in incidences, the number of burning-free villages increased consistently due to IEC activities, CRM machinery support, and farmer awareness programs by KVK Rohtak (Figure 1). The transition from 95 burning-free villages in 2018-19 to 125 in 2024-25 reflects successful behavioural change among farmers. Most

villages are now dominated by CRM practices, with over 80% of the cultivated area managed under CRM and only a marginal share remaining under conventional residue management, reflecting a clear and significant shift in farmers' behaviour. Overall, the trend signifies the wide-scale adoption of CRM technologies, substantially minimizing residue burning in the district.

**Fig 1:** Number of burning-free villages, burning free area, and in-situ rice residue management in Rohtak district (2018-2025)

The total rice cultivation area increased steadily from around 48,000 ha in 2018-19 to over 84,000 ha in 2024-25 (Figure 1). Correspondingly, the burning-free area also showed a rising trend, indicating enhanced adoption of sustainable practices. In-situ rice residue management expanded gradually, reflecting greater mechanization and awareness among farmers. The data suggests that integrated crop residue management practices contributed to reducing stubble burning while maintaining rice production. Overall, the figure highlights the positive impact of awareness programs and government interventions in promoting environmentally sustainable rice cultivation.

### IEC activities, farmer participation, machinery purchased and Custom Hiring Centers (CHCs)

The sharp decline in straw burning across Rohtak district can largely be credited to the well-structured Information, Education and Communication initiatives carried out by KVK Rohtak under the crop residue management scheme from 2018-19 to 2024-25. During this period, 131 extension programs were organized across 15 villages, engaging 17,417 participants through a variety of awareness and capacity-building activities. Farmers were trained in the practical use of mulcher, straw chopper, slasher, zero till drill, happy seeder, super seeder and super SMS through 23 specialized training programs involving 753 participants,

while kisan melas drew the highest participation with more than 5,750 farmers. Awareness camps at block and district levels sensitized 3,642 farmers with localized solutions, and over 3,300 students were mobilized in schools and colleges to nurture long-term advocacy. In addition, field days, exposure visits, and demonstrations on 670 hectares provided farmers with hands-on experience, encouraging adoption through peer-to-peer learning. The steady rise in participation highlighted farmers' growing confidence and acceptance of in-situ residue management.

In addition to awareness and capacity-building programs, the purchase of CRM machinery and custom hiring centers played a pivotal role in enabling in-situ residue management. Over the period 2018-19 to 2024-25, a total of 22 machines were purchased by CCSHAU KVK, Rohtak for farmers. The maximum number was recorded for Zero till seed cum fertilizer drill (6 units) and Happy seeder (4 units), both of which are crucial for residue retention and sowing wheat in standing stubbles. Other machines such as rotary mulcher (2 units), reversible M.B. plough (1 unit), rotary slasher (2 units), and straw chopper (1 unit) supplemented residue incorporation and management efforts. To further

strengthen the adoption of crop residue management technologies, Custom Hiring Centres (CHCs) were established in selected villages of Rohtak district by Department of Agriculture and Farmers welfare with substantial financial assistance for CRM machinery procurement. A total of 31 CHCs were established during the period with cumulative financial assistance of ₹157.32 lakh. The maximum support was extended in Rithal village (10 CHCs with ₹53.46 lakh), followed by Madina (5 CHCs, ₹24.70 lakh) and Sanghi (4 CHCs, ₹21.27 lakh). Other villages such as Ajaib, Titoli, Chiri, Baliyana, Kahni, and Nandal also received support, though on a smaller scale. The financial assistance for machinery under CHCs had a multiplier effect, as small and fragmented landholders who could not afford CRM machinery individually were able to access it at nominal rental charges, villages with higher CHC concentration reported faster adoption of no-till in wheat sowing after paddy thereby reducing residue burning, and the decentralized support system created machinery hubs at the village level, ensuring timely availability of equipment during peak sowing season.

**Table 2:** IEC Activities organized by KVK Rohtak under CRM project (2018-19 to 2024-25)

| S. No. | Name of Activity                                            | 2018-19 |              | 2019-20 |              | 2020-21 |              | 2021-22 |              | 2022-23 |              | 2023-24 |              | 2024-25 |              | Grand Total |              |
|--------|-------------------------------------------------------------|---------|--------------|---------|--------------|---------|--------------|---------|--------------|---------|--------------|---------|--------------|---------|--------------|-------------|--------------|
|        |                                                             | No.     | Participants | No.     | Participants | No.     | Participants | No.     | Participants | No.     | Participants | No.     | Participants | No.     | Participants | No.         | Participants |
| 1      | Skill development training on In-Situ CRM                   | 8       | 378          | 2       | 50           | 3       | 75           | 3       | 75           | 3       | 75           | 0       | 0            | 4       | 100          | 23          | 753          |
| 2      | Kisan Mela                                                  | 2       | 2100         | 0       | 0            | 1       | 100          | 1       | 300          | 2       | 1150         | 1       | 1500         | 1       | 500          | 8           | 5750         |
| 3      | Farmer Scientist Interaction                                | 2       | 150          | 0       | 0            | 0       | 0            | 0       | 0            | 0       | 0            | 0       | 0            | 0       | 0            | 2           | 150          |
| 4      | District Level Awareness Camp                               | 3       | 838          | 1       | 200          | 1       | 100          | 1       | 200          | 2       | 300          | 0       | 0            | 1       | 250          | 9           | 1888         |
| 5      | Block Level Awareness Camp                                  | 3       | 609          | 2       | 200          | 2       | 145          | 2       | 200          | 2       | 200          | 2       | 200          | 2       | 200          | 15          | 1754         |
| 6      | Village Level Awareness Camp                                | 13      | 508          | 5       | 250          | 6       | 330          | 4       | 200          | 4       | 200          | 1       | 50           | 3       | 150          | 36          | 1688         |
| 7      | Mobilization of School Students                             | 2       | 400          | 2       | 200          | 2       | 200          | 2       | 200          | 3       | 300          | 3       | 300          | 4       | 400          | 18          | 2000         |
| 8      | Mobilization of College Students                            | 1       | 280          | 1       | 100          | 0       | 0            | 1       | 175          | 2       | 300          | 1       | 150          | 2       | 300          | 8           | 1305         |
| 9      | Field Days on CRM Technologies                              | 0       | 0            | 0       | 0            | 3       | 120          | 3       | 450          | 3       | 300          | 1       | 24           | 2       | 50           | 12          | 944          |
| 10     | Exposure visit of farmers                                   | 3       | 145          | 1       | 12           | 0       | 0            | 2       | 220          | 2       | 208          | 0       | 0            | 2       | 100          | 10          | 685          |
| 11     | Demonstrations conducted using different CRM Machinery (ha) | 100     | 250          | 0       | 0            | 120     | 225          | 150     | 325          | 100     | 175          | 0       | 0            | 200     | 200          | 670         | 1175         |

### Demonstrations on CRM technologies and adoption of CRM machinery

KVK Rohtak conducted frontline demonstrations (FLDs) on use of happy seeder, super seeder, zero drill, mulcher and slasher in paddy-wheat system to showcase residue incorporation, retention, and sowing efficiency. The economic comparison of wheat establishment methods (Table 3) revealed that all CRM-based options outperformed conventional sowing in terms of yield, profitability, and benefit-cost ratio. Conventional sowing recorded a yield of

55 q/ha with net returns of ₹84,594/ha and a B: C ratio of 3.08. Among CRM options, zero till sowing proved most profitable, giving the highest net return (₹93,510/ha) and the maximum B: C ratio (3.75), primarily due to reduced cultivation cost. The super seeder option produced the highest yield (57.5 q/ha), while happy seeder sowing also ensured high profitability with a B: C ratio of 3.58. These results clearly demonstrate that CRM-based wheat establishment methods are economically superior to conventional sowing, offering both higher productivity and

better returns to farmers. The operations of zero till drill use less time and energy than traditional tillage methods, which

lowers total cost of cultivation and reduces possibility of *Phalaris minor* in wheat crop.

**Table 3:** Economic comparison of conventional vs. CRM-based wheat establishment methods

| Technology Option                    | Yield (q/ha) | Gross cost (Rs/ha) | Gross return (Rs/ha) | Net Returns (Rs /ha) | B: C Ratio |
|--------------------------------------|--------------|--------------------|----------------------|----------------------|------------|
| Conventional sowing                  | 55.00        | 40532              | 125125               | 84594                | 3.08       |
| Manual harvesting + Zero till sowing | 56.00        | 33890              | 127400               | 93510                | 3.75       |
| SMS Combine + Happy seeder sowing    | 56.50        | 35860              | 128538               | 92678                | 3.58       |
| SMS Combine + Super seeder sowing    | 57.50        | 37202              | 130812               | 93610                | 3.52       |

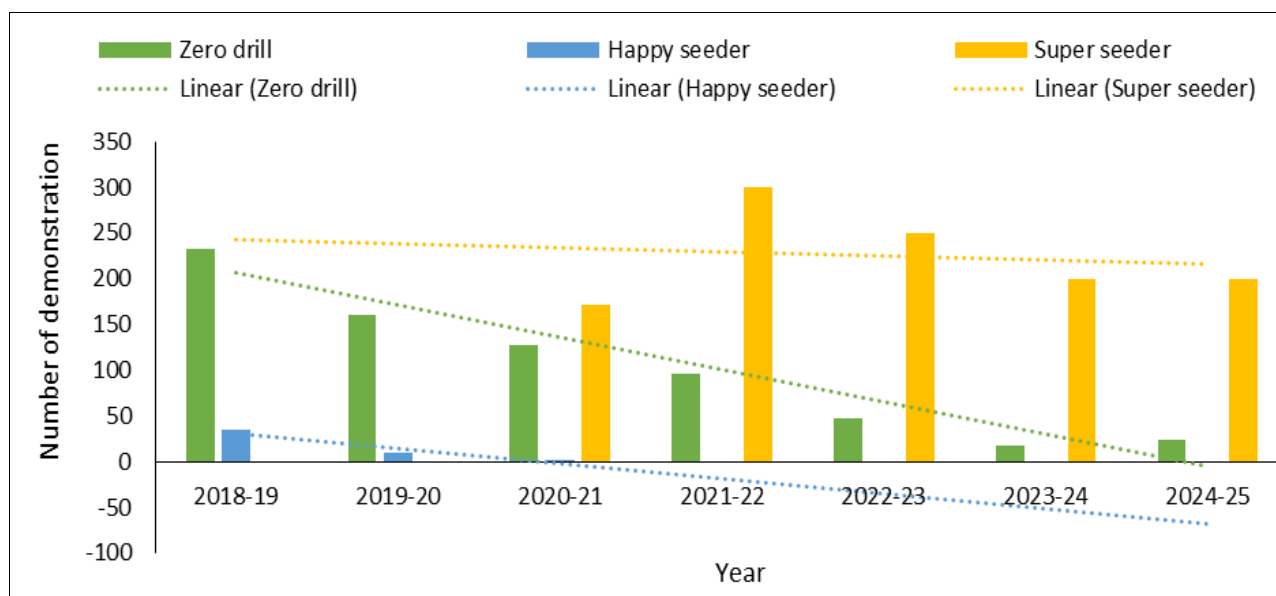


**Fig 2:** Pattern of CRM machinery used by farmers in Rohtak district during 2018-2025

The pattern of CRM machinery use in Rohtak district during 2018-2025 (Figure 2) shows a clear shift in farmers' preferences. Demonstrations with the zero drill were dominant in the initial years (2018-19), but gradually declined thereafter, reflecting reduced adoption over time. The happy seeder had only a limited share, with its demonstrations decreasing consistently across the period. In contrast, the super seeder emerged as the most preferred technology from 2020-21 onwards, with demonstrations peaking in 2021-22 and maintaining a higher level compared to other options. The trend lines confirm the decline of zero drill and happy seeder, while the super seeder remained stable with consistently higher adoption.

## Discussion

The findings of the present study clearly demonstrate that large-scale adoption of crop residue management (CRM) practices in Rohtak district has significantly contributed to the sustainability of the paddy-wheat system. The interventions undertaken by KVK Rohtak, including awareness programs, capacity building, demonstrations, and provision of mechanization support, played a crucial role in shaping farmer behaviour and ensuring a gradual reduction in stubble burning while maintaining productivity levels. The steady expansion of paddy area and production after 2018, despite relatively stable yields, highlights the impact of CRM interventions in maintaining soil fertility and stabilizing crop performance under climate variability. While expansion in cultivated area is often associated with increased residue loads and potential burning, the

concurrent rise in CRM adoption in Rohtak helped mitigate this challenge by ensuring in-situ residue utilization. These results indicate that crop residue management not only contributes to improved soil health and input use efficiency but also supports food and nutritional security by enabling higher grain contributions to the central pool.

The remarkable decline in crop residue burning incidents from 53 in 2018-19 to just 14 in 2024-25, despite a 76% increase in paddy area, underscores the effectiveness of CRM interventions. This aligns with state-wide trends in Haryana, where burning events dropped substantially from 9,225 to 1,055 during the same period. Rohtak's fluctuating but generally low share of burning cases relative to the state average indicates that the district's efforts were well-synchronized with broader policy and programmatic initiatives. The findings corroborate earlier reports that total number of crop residue burning cases recorded in Haryana state was 10286 in the year 2018-19 which decreased to 3661 in the year 2022-23 (Singh *et al.* 2023) [16]. Another significant outcome of the study is the consistent increase in burning-free villages, rising from 95 in 2018-19 to 125 in 2024-25. This reflects successful behavioural change among farmers driven by IEC activities, demonstrations, and easy access to machinery. The predominance of CRM practices across most villages, with more than 80% of area under in-situ management, indicates a cultural and attitudinal shift toward sustainable farming practices. These findings are consistent with Singh *et al.* (2024) [14], who observed a sharp rise in in-situ residue management adoption from 13.6% to 92.6% in recent years.

The IEC strategy proved instrumental in creating widespread awareness about the ill effects of residue burning and the benefits of CRM technologies. With over 17,000 participants engaged through structured extension activities, the program fostered both knowledge enhancement and skill development. Specialized trainings, Kisan Melas, awareness camps, and student mobilization initiatives contributed to a comprehensive knowledge ecosystem. Importantly, peer-to-peer learning through field demonstrations further enhanced adoption rates. The present findings support earlier studies emphasizing the role of awareness campaigns and community mobilization in altering farmer perceptions and practices (Singh *et al.*, 2020; Devi *et al.*, 2017) <sup>[17]</sup>. Machinery purchase and the establishment of Custom Hiring Centers (CHCs) created an enabling environment for residue management. Access to happy seeder, super seeder, zero till drills, and mulchers provided operational solutions for in-situ residue incorporation and direct seeding. The establishment of 31 CHCs with substantial financial assistance made CRM technologies accessible to smallholders at nominal rental rates, which is crucial in a district with fragmented landholdings. This decentralized machinery support system not only promoted wider adoption but also ensured timeliness of operations, and such results are in line with reports highlighting the role of CHCs in accelerating diffusion of conservation technologies across rural landscapes.

Frontline demonstrations further revealed the economic superiority of CRM-based wheat establishment methods over conventional tillage. Among the technologies, zero till sowing provided the highest profitability due to reduced cultivation costs, while super seeder produced the highest yields. Happy seeder sowing also emerged as a viable option with high benefit-cost ratios. These findings corroborate Mishra *et al.* (2021) <sup>[8]</sup>, who highlighted the efficiency of zero till drills in managing anchored stubbles while lowering costs and weed pressure, particularly *Phalaris minor*. Thus, the economic advantage serves as a strong incentive for farmers to shift toward CRM technologies. The evolving pattern of machinery use in Rohtak illustrates changing farmer preferences over time. While zero till drills dominated initially, their adoption gradually declined. The happy seeder showed only limited uptake, whereas the super seeder emerged as the most preferred option from 2020-21 onwards, maintaining higher levels of adoption. This aligns with the findings of Buttar *et al.* (2023) <sup>[2]</sup>, who reported that the adoption of happy seeder was maximum (16.80%) among different technologies during 2019 while super seeder was preferred and accepted on a large scale (14.99%) during 2020. Such trends underline the importance of continuous technological adaptation and farmer-centric demonstrations to guide adoption decisions.

### Integrated outcomes of CRM interventions

The integrated outcomes of CRM interventions in Rohtak district highlight a holistic transformation encompassing environmental, soil health, and socio-economic dimensions. The systematic convergence of area expansion, reduced straw burning (73% decline between 2018-25), machinery adoption, and intensive IEC efforts has created a strong

technology-behaviour-policy nexus. Environmentally, the sharp decline in straw burning has reduced seasonal air pollution, while in-situ residue incorporation-adopted on more than 70% of rice fields by 2024-25-has curtailed greenhouse gas emissions and improved soil moisture conservation. Soil health improvements were evident through enhanced microbial activity, better nutrient cycling, and gradual increases in soil organic carbon, ultimately boosting fertility. These ecological gains translated into economic benefits, with farmers reporting savings of ₹2,000-3,000 per ha due to reduced land preparation, fuel, labour, and irrigation costs. Furthermore, access to government subsidies, machinery banks, and collective demonstrations empowered farmer groups, while the reduction in stubble burning contributed to improved public health outcomes by lowering air pollution. Together, these outcomes demonstrate how CRM has fostered sustainable intensification of the paddy-wheat system while improving farmer livelihoods and environmental quality.

### Conclusion

The study concludes that sustained CRM interventions in Rohtak district-through government support, KVK initiatives, machinery distribution, CHC establishment, and intensive IEC activities-have significantly reduced crop residue burning, improved soil health, and enhanced the sustainability of the paddy-wheat system. While challenges remain, particularly in ensuring equitable access and behavioural change among smallholders, the district is steadily progressing toward a “zero burning” status and can serve as a model for other regions in Haryana and Punjab. Continued emphasis on policy support, technological innovations, crop diversification, and inclusive participation of farmers, youth, and women will be crucial for sustaining these gains and achieving long-term environmental and socio-economic benefits.

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