

Harvesting change: Tech-driven solutions for paddy residue management

Rajbir Singh* and S. N. Jha

Indian Council of Agricultural Research, New Delhi 110 012

The management of paddy residue in northwest India, particularly Punjab, Haryana, and Uttar Pradesh, constitutes a critical environmental and agricultural challenge owing to large-scale residue burning, which causes severe air pollution, soil degradation, and health risks. To address this, a range of farm machineries, such as the Super SMS attachment, Happy Seeder, Smart Seeder, Surface Seeder and Super Seeder, have revolutionized in situ rice residue management practices. Supported by robust government schemes and extensive Information, Education, and Communication (IEC) initiatives led by Krishi Vigyan Kendras, these mechanized solutions have resulted in an impressive reduction of residue burning incidents between 2020 and 2024. A detailed economic evaluation highlights the cost-effectiveness and ecological sustainability of these methods compared to conventional burning. Short-duration rice varieties and crop diversification serve as pivotal strategic interventions to effectively reduce residue generation. The integration of technological innovation, robust policy frameworks, and heightened farmer awareness collectively paves a transformative pathway towards sustainable conservation agriculture, promoting enhanced productivity, environmental stewardship, and the long-term resilience of the rice-wheat cropping system in this crucial agrarian region.

Keywords: Conservation agriculture, IEC activities, *In situ*, Paddy residue management

THE states of Punjab, Haryana, and western Uttar Pradesh are crucial for India's food security, playing a major role in the production of paddy and wheat. However, these areas are now facing a serious environmental and agricultural issue of managing paddy residue. With about 4.2 million hectares of paddy fields in Punjab and Haryana, the amount of paddy residue produced is huge. Due to the very short time between harvesting paddy and sowing wheat, many farmers feel they have no choice but to burn the leftover straw in their fields. The burning occurs mainly within a span of 15–20 days, releasing large amounts of pollutants into the air, which leads to serious environmental pollution, loss of nutrients, and damage to soil and human health. Scientific studies show that burning one tonne of paddy straw produces around 3 kg of particulate matter (PM), 60 kg of carbon monoxide (CO), 1,460 kg of carbon dioxide (CO₂), 199 kg of ash, and 2 kg of sulphur dioxide (SO₂). These emissions significantly worsen air quality, creating serious health risks for both humans and animals by worsening respiratory, heart, and other chronic diseases. Considering the vital role of this

agricultural region and the urgency of the problem, it is essential to adopt innovative, sustainable, and farmer-friendly methods for managing crop residue.

Recognizing the gravity of the issue concerning crop residue burning, the Ministry of Agriculture and Farmers' Welfare of the Government of India initiated the central sector scheme titled "Promotion of Agricultural Mechanization for *in situ* Management of Crop Residue in the States of Punjab, Haryana, Uttar Pradesh, and the NCT of Delhi" in the fiscal year 2018–19. The scheme's primary aim is to comprehensively promote agricultural mechanization to facilitate the *in situ* management of crop residue by fostering awareness and building capacity among farmers. As part of this initiative, individual farmers are provided with 50% financial support for acquiring agricultural machinery, while Farm Machinery Banks or custom hiring centres for crop residue management (CRM) are established with an 80% subsidy on the overall project cost. The Indian Council of Agricultural Research (ICAR), through its network of 60 Krishi Vigyan Kendras (KVKs) across Punjab (22), Haryana (14), Delhi

(1), and Uttar Pradesh (23), has been assigned the task of executing Information, Education, and Communication (IEC) activities under the CRM project.

Table 1. Details of major Information, Education and Communication (IEC) activities under CRM Project from 2018–19 to 2024–25

IEC Activities	Conducted	Beneficiary
Awareness programmes (District/ Block/ Village Level)	4,487	3,55,347
Training programmes	1,417	49,012
Kisan Melas on CRM	380	8,20,390
Mobilization of school and college students	1,841	2,28,383
Demonstrations on CRM machinery (1 ha each)	78,054	1,36,308
Exposure visits	996	41,966
Field/ Harvest days	1,146	59,452

Since its inception in 2018, ICAR through its network of KVKs, a total of 4,487 awareness programmes, 454 Kisan Melas, 996 exposure visits, and 1,146 field and harvest days have been conducted, encouraging over 1.95 million farmers and stakeholders to adopt *in situ* CRM technologies. In an effort to broaden their outreach, 1,841 educational institutions have been engaged, mobilizing more than 2.25 lakh students to ensure that the message against crop residue burning permeates households and local communities. Various social media platforms, including WhatsApp, Facebook, and YouTube, alongside traditional media such as posters, banners, wall writings, news articles, and television and radio broadcasts, have been effectively utilized to raise awareness among 1.8 million farmers. Acknowledging the necessity for skilled personnel, ICAR-KVKs have conducted 1,417 capacity-building programmes, each spanning five days, training approximately 49,012 farmers, tractor operators, and machine bank operators. These trained individuals are anticipated to operate CRM machinery and provide assistance to fellow farmers in their communities. Additionally, the KVKs have carried out over 78,000 demonstrations of CRM machinery on more than 136,000 farmers' fields, offering practical experience on how to cultivate crops without burning paddy residue.

Tools of transition: Managing residues with mechanisation

Punjab Agricultural University (PAU), Ludhiana has developed and recommended different farm machineries for the efficient management of paddy straw, applicable both in-field and for off-field utilization. Paddy straw can be managed within the field either by using it as surface mulch or by incorporating it into the soil. This *in situ* management approach retains essential nutrients such

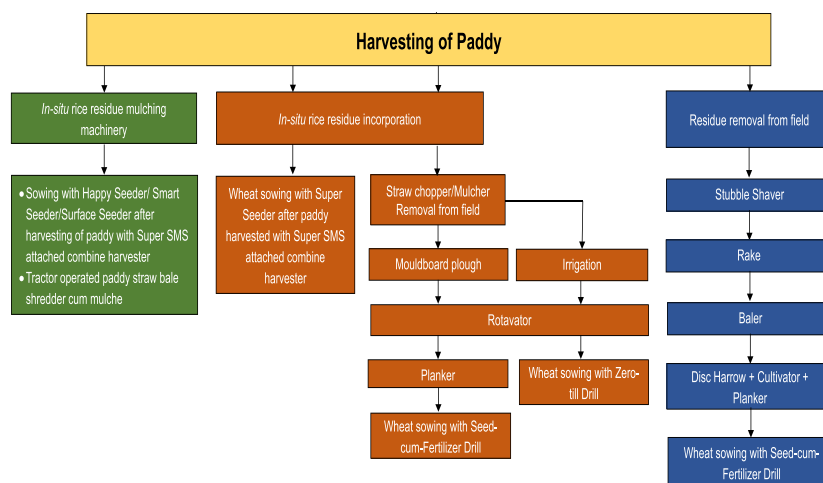
as N, P, K, S and organic carbon, thereby improving soil fertility and health. Also, continuous adoption of these *in situ* straw management practices not only prevents residue burning but also leads to a significant increase in the productivity of the rice-wheat cropping system, promoting sustainable and environmentally friendly agriculture in the region.

Machinery for *in situ* rice residue mulching

Super straw management system: To ensure the effective operation of *in situ* mulching machines such as the Surface Seeder, Smart Seeder or Happy Seeder in combine-harvested paddy fields, PAU, Ludhiana developed the Super Straw Management System (SMS) attachment which is fitted behind the straw walkers of the combine harvester and mounted at its rear end. The straw coming out of the walkers is directed into the unit, where it is chopped by flail blades mounted on a rotating shaft. For smooth operation, it is important that all rotating parts such as blades, bushes, plates and bolts are of the same dimensions to ensure proper fitting. Any mismatch can cause vibrations in the unit. Dynamic balancing of the rotor is also necessary to minimize vibration at high speeds. The Super SMS attachment should be firmly supported by the chassis of the combine harvester to reduce overhang and mechanical stress. In addition, the V-belt and pulley system should be chosen carefully so that belt slippage remains within acceptable limits.

Happy seeder: The Happy seeder is a machine designed to sow wheat directly into combine-harvested paddy fields. It is a tractor PTO driven machine which can be operated by 45 hp or above tractor and can cover 0.33–0.38 ha/h. In a single operation, the Happy seeder cuts the standing straw in front of its furrow openers and places it over the sown wheat crop. This layer of straw serves as mulch, helping to conserve soil moisture and improve soil health. For best results, the loose residue should be spread evenly in the field before operating the Happy seeder.

Smart seeder: Smart Seeder manages the rice residue by shallow incorporation and surface mulching. The machine sows wheat seeds in a narrow, well-tilled



Smart paddy straw management and direct wheat seeding solutions

strip of soil and then covers the seed rows using furrow-closing rollers. The furrow closing roller also acts as depth control mechanism for sowing wheat. It is a PTO driven machine operated by 45 hp or above tractor and it covers about 2.8–3.2 ha/day.

Surface seeder: Surface Seeder comprises of a straw cutter-cum spreader fitted with seed and fertilizer box attachment. This machine can be easily operated by the 40 hp tractor or above. It is an economical machine designed to cut and spread paddy straw while sowing wheat seed and applying fertilizer in a single operation. It is followed by light irrigation for initiating the germination of wheat. Operate the machine with 4–5 inches above the soil at proper speed to spread seed and fertilizer evenly, ensuring seeds are covered with paddy mulch.

Tractor operated paddy straw bale shredder-cum-mulcher: Tractor operated paddy straw bale shredder cum-mulcher can be used for reducing straw size of a straw bale and spreading it uniformly in the field for mulching in widely spaced crops. This machine will reduce dependence on labour for mulching and reduce straw size thereby effective in controlling weeds. This machine can be easily operated by the 35 hp tractor or above with average field capacity of 0.25 ha/h.

Machinery for *in situ* rice residue incorporation

Super seeder: Tractor operated Super Seeder is a machine used for direct sowing of wheat in combine harvested paddy field. The machine is a combination of roto seed drill and disc type seeding attachment. The machine is equipped with a straw management rotor, fitted with flanges carrying six blades each, which chop and mix the straw into the soil. Machine is operated by a 55 hp or above tractor.

Paddy straw chopper-cum-spreader: This machine chops and spreads straw left after combine harvesting in a single pass, using a 45 hp or above tractor with capacity of 0.32–0.35 ha/h. If sufficient moisture is present after paddy harvesting, incorporate the chopped straw into the soil with mouldboard plough and prepare the field with a rotavator. If 2–3 weeks are available before wheat sowing depending upon soil type, apply shallow irrigation and mix the straw using disc harrow or rotavator.

Machinery for collection of rice residues

Straw baler: The straw baler collects loose paddy straw and compresses it into rectangular or round bales for easy handling. Before baling, standing stubbles are reaped with stubble shaver to facilitate smooth baler



Farm machinery involved in paddy residue maangement; (i) PAU Super SMS attached combine harvester; (ii) Happy Seeder; (iii) PAU Smart Seeder; (iv) Paddy Straw Bale Shredder-cum-Mulcher; (v) PAU Surface Seeder; (vi) Super Seeder; (vii) Mouldboard plough; (viii) Paddy straw chopper; (ix) Baler

operation. Square balers produce bales 40–110 cm long, weighing 15–25 kg depending on moisture content, with a field capacity of 0.7–0.72 ha/h. Large round balers make heavier bales of 300–500 kg, with a standard width of 120 cm and bale diameter varies from 90–180 cm. These bales are useful for power generation, compressed biogas, bio-ethanol, composting and mulching. They can also be used in making cardboard and packaging materials.

Rake: The rake is used to collect loose stubbles and form windrows with rotary spikes powered by the tractor PTO. It is operated after the stubble shaver to collect loose straw in the field efficiently. This reduces the number of baler turns in the field and increases field capacity.

Paddy straw bales have become a vital resource for energy and industrial applications, effectively transforming agricultural residue into economic assets. These bales are extensively utilized in biomass power plants, paper manufacturing units, and industrial boilers and alternative to conventional fuels. Furthermore, the production of paddy straw pellets for brick kilns is gaining traction, reducing the reliance on coal and mitigating pollution. The bio-CNG and ethanol plants have also started using these paddy bales.

Table 2. Economic analysis of different methods of wheat sowing

Method	Machines	Operational cost (₹ /ha)
Conventional method (Burning of paddy residue)	Stubble Shaver + Disc Harrow × 2 + Cultivator × 2 + Planker + Seed Drill	8,875
<i>In situ</i> paddy residue management	Super SMS + Happy Seeder	4,400
	Super SMS + Smart Seeder	4,550
		6,075
<i>Ex situ</i> paddy residue management	Super SMS + Super Seeder	13,600
	Chopper/ Mulcher + MB Plough + Rotavator + Planker + Seed Drill	8,350
	Chopper/ Mulcher + Light Irrigation + C type blade Rotavator + Zero till drill	1,750–2,250
	Surface Seeder	10,225
	Stubble Shaver + Rake + Baler + Disc Harrow + Cultivator + Planker + Seed Drill	

Comparative cost analysis of different wheat sowing methods

The comparative analysis of various paddy residue management methods reveals a clear shift from the traditional practice of residue burning towards more sustainable, cost-efficient, and environmentally responsible approaches. Conventional burning, though convenient, incurs higher operational costs (₹ 8,875/ha)

and leads to severe ecological damage. In contrast, *in situ* residue management techniques such as the use of Super SMS with Happy Seeder or Smart Seeder not only reduce costs significantly (₹ 4,400–6,075/ha) but also enhance soil health and moisture retention. Among these, surface seeding stands out as the most economical option (₹ 1,750–2,250/ha), offering a simple yet effective solution for farmers. Meanwhile, *ex situ* management through straw collection and baling (₹ 10,225/ha) provides a pathway for utilizing residues as biofuel or compost.

Role of short-duration rice varieties in sustainable paddy residue management

Several short-duration rice cultivars have been developed and promoted to ensure the timely vacating of fields for proper rice residue management that also have low biomass which again helps in easy *in situ* or *ex situ* management of rice residue. Among these paddy varieties, PR 126, which matures in about 93 days after transplanting, and PR 130, maturing in around 105 days after transplanting, generate only 36.1 q/acre of straw, thereby substantially reducing residue load in the fields. Similarly, other improved short-duration varieties such as PR 114 (matures in about 115 days, 36.7 q/acre straw load), PR 121 (about 119 days, 36.3 q/acre), PR 128 (about 111 days, 36.9 q/acre), and PR 131 (about 110 days, 36.7 q/acre) also provide a balanced grain yield while producing less straw.

Role of crop diversification

Crop diversification plays a transformative role in paddy residue management by reducing the extensive mono-cropping of paddy, which contributes significantly to residue accumulation and stubble burning. By shifting portions of paddy cultivation to alternative crops such as pulses, maize, cotton, and oilseeds, crop diversification not only lowers the volume of paddy straw residue but also breaks the cycle of ecological degradation caused by excessive water use. This strategy enhances farmers' income opportunities and strengthens environmental sustainability by decreasing the urgency for open-field burning, facilitating better residue utilization practices, and improving soil health. Government incentives and mechanization support further promote this shift, enabling farmers to adopt diversified cropping patterns that mitigate air pollution and contribute to climate resilience in Punjab's agrarian landscape.

Managing crop residues at farm level

With collective efforts from all quarters in effectively engaging, educating and empowering farmers through “Push, Pull and Enforcement” mechanism with due consideration of incentives to adopting *in situ* CRM practices, there has been a notable decline in crop-burning incidents, with reductions of 10% in 2021, 38% in 2022, 53% in 2023, and 80% in 2024 compared to the baseline year of 2020 (from September 15 to November 30). Specifically, the northwest region experienced an overall decrease of 65% in residue burning events



Combo technology of super SMS fitted combine and sowing of wheat with Happy Seeder

compared to 2023. In Punjab, a consistent downward trend has been observed, with reductions of 14% in 2021, 40% in 2022, 56% in 2023, and 87% in 2024 relative to the 2020 burning events (83,002 events). The impact of these initiatives is further illustrated by the adoption of *in situ* residue management practices in Punjab, which resulted in cost savings of ₹ 538 crores by lowering cultivation expenses, conserving farm nutrients valued at ₹ 495 crores through residue retention, and saving at least one irrigation cycle, thereby preventing the extraction of 571 million cubic meters (MCM) of groundwater. Most significantly, over the past seven years, more than 1,350 villages have been supported by ICAR-KVKs, with over 350 villages successfully transformed into “Burning Free Villages.”

Way forward

The sustainable management of paddy residue presents both a crucial challenge and a pivotal opportunity to enhance agricultural productivity while safeguarding environmental health. Moving forward, the focus must be on scaling up farmer education and expanding access to affordable, cutting-edge mechanization that facilitates efficient *in situ* residue management, especially for smallholder farmers. Promoting crop diversification and short-duration rice varieties will reduce residue accumulation and enable timely sowing of subsequent crops. Additionally, leveraging innovative residue utilization avenues such as bioenergy, organic compost, and industrial raw materials can transform waste into value-added products, providing economic incentives for farmers. Strengthening policy support, fostering multi-stakeholder collaboration among government, research institutions, and communities, and employing robust monitoring systems for adaptive management are

essential to sustain and accelerate progress. Together, these integrated strategies will drive the evolution of a resilient, eco-friendly, and economically viable agrarian system in north-western India, ensuring long-term environmental sustainability and farmer prosperity.

SUMMARY

The management of paddy residue stands as a pivotal environmental and agricultural challenge in north-west India, particularly in the states of Punjab, Haryana, and Uttar Pradesh, which are crucial for India's food security. The traditional practice of open-field burning of paddy straw, while convenient for farmers, results in severe air pollution, soil degradation, and significant health hazards. The integration of advanced farm machinery, combined with robust government schemes and intensive Information, Education, and Communication (IEC) campaigns led by Krishi Vigyan Kendras, has revolutionized *in situ* crop residue management. These innovations have achieved impressive reductions in residue burning incidents, demonstrating both economic viability and ecological sustainability. The successful adoption of these paddy residue management farm machineries, along with strategic crop diversification and promotion of short-duration rice varieties, offer transformative pathways towards conservation agriculture. This multi-faceted approach not only curtails pollution but also improves soil health and boosts productivity of the rice-wheat cropping system. Continued policy support, farmer awareness, and technological advancements remain essential to sustain this positive trend, ultimately securing a cleaner environment and resilient agrarian economy for the region.

*Corresponding author email: ddg-extn.icar@gov.in