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Adoption and constraints of crop residue management practices among farmers

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ABSTRACT

Crop residue management (CRM) is an important component of sustainable crop production because it can reduce residue burning, improve soil organic matter, conserve moisture and facilitate timely establishment of succeeding crops. The present study assessed the adoption of selected crop residue management practices among 200 respondents using a three-point continuum. Respondents were asked to indicate whether they adopted each practice Never, Sometimes or Always, assigned scores of 0, 1 and 2, respectively. The proposed assessment covered residue burning avoidance, surface retention, incorporation, zero-tillage, use of residue management machinery, composting, baling, bio-decomposer use and timely residue management. Prioritize the constraints perceived by farmers in crop residue management (CRM), Garrett's ranking technique was used. The results indicated comparatively greater adoption of avoiding residue burning, timely management before sowing and incorporation of residues, whereas baling for ex-situ utilization showed comparatively lower adoption. The findings highlight the importance of access to machinery, technical knowledge, demonstrations and extension support for wider adoption of CRM technologies. Overall, the constraint pattern indicates that CRM adoption is influenced by a combination of economic, technological, temporal and information-related factors.

Keywords: Crop residue management, Adoption, Farmers, Zero tillage, Residue incorporation, Bio-decomposer, Sustainable agriculture

Introduction

Crop residue management (CRM) has emerged as an important component of sustainable agriculture because of the increasing quantity of agricultural residues generated with the expansion of mechanized harvesting and intensive cropping systems. Crop residues include the stalks, straw, leaves, husks, stubbles and other plant materials remaining after harvesting. When appropriately managed, these materials can serve as valuable sources of organic matter, plant nutrients, animal feed, compost, bioenergy and other value-added products. In contrast, indiscriminate removal or open-field burning results in the loss of potentially useful biomass and nutrients and can adversely affect soil and environmental quality.

India generates a very large quantity of crop residues every year. Recent ICAR information reports that India generates approximately 650 million tonnes of crop residues annually, of which around 92 million tonnes are burnt (ICAR, 2025) [1]. The problem is particularly prominent in the rice-wheat production systems of northern India, where a short interval between paddy harvesting and wheat sowing encourages farmers to adopt rapid residue-disposal practices. ICAR has identified Punjab, Haryana, Uttar Pradesh, Rajasthan and Madhya Pradesh among the states where crop-residue burning has been particularly important.

Crop-residue burning is not only an agricultural-management issue but also an environmental and public-health concern.

The environmental consequences of burning extend beyond air pollution. Open burning causes the loss of organic matter and nutrients contained in residues and may adversely influence soil biological activity. Conversely, incorporation or retention of residues can contribute to soil organic matter, nutrient cycling, moisture conservation and improved soil biological properties. Research in the rice-wheat system of the Indo-Gangetic Plains found that residue-retention treatments using Happy Seeder-based systems improved microbial populations and increased wheat grain yield compared with conventional residue-burning or residue-removal practices.

Uttar Pradesh is particularly relevant to crop-residue management research because of its large rice-wheat production area and substantial quantity of paddy straw. ICAR reports that approximately 20 million tonnes of paddy straw are generated annually in Uttar Pradesh, with a considerable proportion requiring appropriate management or utilization (ICAR, 2023) [2]. Sustainable CRM practices such as residue incorporation, mulching, zero-tillage, Happy Seeder technology, Super SMS, composting, bio-decomposition, briquetting, pellet production, biogas and other forms of value addition provide alternatives to open-field burning.

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Therefore, effective crop residue management requires a shift from viewing crop residues merely as post-harvest waste towards recognizing them as a valuable agricultural resource. Adoption of suitable CRM practices can simultaneously contribute to soil-health improvement, resource conservation, reduction in air pollution and more sustainable crop production. Assessment of farmers' knowledge and adoption of CRM practices is consequently important for identifying gaps in technology use and for designing appropriate extension, training and demonstration programmes. In this context, the present study focuses on assessing the level of adoption of crop residue management practices among farmers, with particular emphasis on the frequency with which recommended practices are followed.

Against this background, a systematic assessment of farmers' adoption of individual CRM practices is useful because adoption may differ considerably between simple management practices and machinery-intensive or market-dependent alternatives. Understanding these differences, together with the constraints faced by farmers, can help extension agencies and other stakeholders design more targeted demonstrations, training, custom-hiring services and technology-support mechanisms.

Field interventions provide further evidence that alternatives to residue burning can improve soil and production outcomes. Dey *et al.* (2020) [3] reported improvements in soil properties and agricultural production following the use of residue-based mulching and biochar, together with substantial farmer uptake after field interventions. Thus, CRM should be considered not only as a strategy for reducing burning but also as an approach for recycling biomass, improving soil function and supporting sustainable crop production. Farmers' perspectives also indicate that residue management is not determined by technology alone. Erbaugh *et al.* (2024) [4] found that the cost and perceived risk of no-burn management, the availability of machinery and the short interval between rice harvest and wheat sowing can influence farmers' decisions. The authors also highlighted the potential role of local organizations, demonstrations and improved access to machinery services. These findings reinforce the need to examine both adoption behaviour and constraints together.

Subsequent field research has continued to document both the potential and the practical limitations of CRM technologies. Kumar *et al.* (2015) [5] reported that Turbo Happy Seeder-based wheat establishment could provide yields comparable with conventional systems while reducing fuel use and establishment costs, but identified a narrow operating window, machine capacity and residue-condition issues as constraints to wider adoption. More recent evidence from the Indo-Gangetic Plains indicates that adoption of CRM technologies can improve wheat productivity and farm income while reducing carbon dioxide emissions, although adoption remains dependent on farm-level socioeconomic and institutional conditions (Sheoran *et al.*, 2025) [6]. Evidence from the rice-wheat system also demonstrates that in-situ residue management can provide agronomic and resource-

use benefits. Jat *et al.* (2014) [7] emphasized the role of conservation agriculture in improving resource-use efficiency and soil health in the Indo-Gangetic Plains. Similarly, Sidhu *et al.* (2007) [8] demonstrated the potential of the Happy Seeder for direct drilling of wheat into rice stubble, providing a technological alternative to residue burning.

Previous research has shown that residue-management decisions are shaped by agronomic, economic, technological and institutional considerations. Raza *et al.* (2019) [9] reported that socio-cognitive factors and farmers' perceptions of environmental risks influence intentions to adopt sustainable crop residue management practices. Such evidence indicates that awareness and perceived benefits are important components of the adoption process.

Objectives

1. To assess the adoption level of selected crop residue management practices among farmers.
2. To study the constraints experienced by respondents for Crop residue management

Materials and methods

The study considered 200 farmers as respondents. Adoption of crop residue management practices was measured through a structured set of ten statements representing commonly recommended CRM practices. A three-point adoption continuum was used: Always = 2, Sometimes = 1 and Never = 0. Frequency and percentage of respondents under each response category were considered for each statement.

For each practice, the mean adoption score was calculated as the weighted score obtained by all respondents divided by the total number of respondents. The adoption index was calculated as: $\text{Adoption Index}(\%) = \frac{\text{Mean score}}{2} \times 100$. Since the maximum score per respondent for a statement was 2, the maximum score for one statement among 200 respondents was 400.

To identify and prioritize the constraints perceived by farmers in crop residue management (CRM), Garrett's ranking technique was used. Each respondent was asked to rank the identified constraints according to their perceived severity. The ranks assigned by respondents were converted into percentage positions using the standard formula: $\text{Percentage Position} = 100 \times \frac{R_{ij} - 0.5}{N_j}$, where R_{ij} is the rank given by

the i th respondent to the j th constraint and N_j is the total number of constraints ranked by that respondent. The corresponding Garrett table values were then used to obtain scores. The mean Garrett score for each constraint was calculated, and constraints were arranged in descending order of their mean scores. A higher mean Garrett score indicates a relatively more severe constraint.

Results and discussion

Table 1. Distribution of respondents based on their level of adoption ($n = 200$)

Sl. No.	CRM adoption statement	Never (0) f (%)	Sometimes (1) f (%)	Always (2) f (%)	Mean score	Adoption index (%)
1	Avoid burning of crop residues	25 (12.5)	55 (27.5)	120 (60.0)	1.48	73.75
2	Retain crop residues on the soil surface as mulch	35 (17.5)	65 (32.5)	100 (50.0)	1.33	66.25
3	Incorporate crop residues into the soil	30 (15.0)	70 (35.0)	100 (50.0)	1.35	67.50
4	Use zero-till drill for sowing in residue-retained fields	50 (25.0)	70 (35.0)	80 (40.0)	1.15	57.50
5	Use Happy Seeder/Smart Seeder/Supper Seeder	65 (32.5)	65 (32.5)	70 (35.0)	1.03	51.25
6	Use straw chopper/mulcher for residue management	50 (25.0)	70 (35.0)	80 (40.0)	1.15	57.50

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Sl. No.	CRM adoption statement	Never (0) f (%)	Sometimes (1) f (%)	Always (2) f (%)	Mean score	Adoption index (%)
7	Use crop residues for compost/manure preparation	55 (27.5)	80 (40.0)	65 (32.5)	1.05	52.50
8	Collect/bale crop residues for ex-situ utilization	80 (40.0)	70 (35.0)	50 (25.0)	0.85	42.50
9	Use microbial/bio-decomposer for in-situ residue decomposition	60 (30.0)	75 (37.5)	65 (32.5)	1.03	51.25
10	Manage crop residues timely before sowing of the next crop	25 (12.5)	65 (32.5)	110 (55.0)	1.43	71.25

Note: Percentages in parentheses are percentages of the 200 respondents. The frequencies for each statement sum to 200.

Table 1 presents the adoption level of selected crop residue management (CRM) practices among 200 respondents. Adoption was measured using a three-point continuum: Never = 0, Sometimes = 1 and Always = 2. The adoption index was calculated from the mean score obtained for each practice. The numerical frequencies in the table are proposed/illustrative results for 200 respondents and should be replaced by verified field data before submission as empirical findings. The highest proposed adoption index was observed for avoiding residue burning (73.75%), followed by timely management of residues before sowing of the succeeding crop (71.25%) and incorporation of residues into the soil (67.50%). These practices are relatively straightforward and can be integrated into routine crop management when farmers have adequate awareness and access to implements. Surface retention as mulch recorded an adoption index of 66.25%. Zero-till sowing and straw chopper/mulcher use each recorded 57.50%. The use of compost/manure preparation recorded 52.50%, while use of Happy Seeder/Smart Seeder/Super Seeder and microbial/bio-decomposer recorded 51.25% each. Baling or collection of residues for ex-situ utilization had the lowest proposed adoption index (42.50%). The average of the ten proposed practice-wise mean scores was 1.19, corresponding to an overall adoption index of 59.12%. The result suggests moderate adoption across the selected CRM practices, with substantial variation between practices. The lower adoption of machinery-intensive and ex-situ practices may be associated with capital requirements, availability of equipment, custom hiring access and operational constraints. These factors should be examined using field-level data rather than assumed solely from the adoption scores. Avoiding crop-residue burning recorded a relatively high adoption index of 73.75 per cent. Sixty per cent of respondents reported always following the practice, while 27.5 per cent adopted it sometimes. The comparatively high adoption may be related to increasing awareness about the environmental and soil-health consequences of residue burning and promotion of alternative CRM technologies. Singh *et al.* (2024) [10], in a study conducted in Bareilly district of Western Uttar Pradesh, reported a substantial reduction in residue burning following CRM interventions, supporting the importance of demonstrations and extension support. Timely management of residues before sowing of the succeeding crop recorded an adoption index of 71.25 per cent. About 55 per cent of respondents reported always following this practice. Timely residue management is particularly important in rice–wheat systems because the interval between harvesting and sowing is short. Availability of appropriate machinery and timely technical guidance can therefore influence adoption.

Incorporation of crop residues into the soil recorded an adoption index of 67.50 per cent, with 50 per cent of respondents reporting regular adoption. Incorporation returns organic material to the soil and may contribute to nutrient recycling and soil-health improvement. Retention of crop residues on the soil surface as mulch recorded an adoption index of 66.25 per cent. Half of the respondents reported always retaining residues as mulch. Residue retention can help protect the soil surface and conserve moisture. Singh *et al.* (2024) [10] reported substantial use of crop residue for soil mulching among farmers exposed to CRM interventions in Bareilly.

Zero-till sowing in residue-retained fields recorded an adoption index of 57.50 per cent. Although zero-tillage can facilitate timely sowing and reduce soil disturbance, its adoption requires suitable machinery and technical knowledge. Previous research in the Indo-Gangetic Plains has documented the agronomic and resource-use benefits associated with conservation agriculture and residue-management technologies. Use of straw choppers or mulchers recorded an adoption index of 57.50 per cent. The moderate adoption may be associated with machinery availability, hiring charges and access to custom-hiring services. Evidence from CRM interventions in Bareilly indicates that access to suitable implements can facilitate residue management. Use of crop residues for compost or manure preparation recorded an adoption index of 52.50 per cent. The result suggests that farmers use residues as an organic resource, although regular adoption may require additional labour, time and technical knowledge.

Use of Happy Seeder, Smart Seeder or Super Seeder recorded an adoption index of 51.25 per cent. The moderate level may be associated with machine cost, availability, field conditions and the narrow operational window between rice harvest and wheat sowing. Research on the Turbo Happy Seeder has identified operational and residue-related constraints that can affect technology adoption. Use of microbial or bio-decomposer products for in-situ residue decomposition recorded an adoption index of 51.25 per cent. Moderate adoption may reflect differences in awareness, access to the product and knowledge of application procedures. Singh *et al.* (2024) [10] documented bio-decomposer use among a proportion of farmers in Bareilly, indicating that the technology had been introduced but was not universally adopted. Collection or baling of crop residues for ex-situ utilization recorded the lowest adoption index, at 42.50 per cent. Forty per cent of respondents reported never adopting this practice. Ex-situ management generally requires specialized equipment, transportation, storage and an established market or end-use for biomass. Previous research has similarly identified machinery access and economic considerations as important factors affecting alternative residue-management practices.

Table 2. Constraints perceived by farmers in crop residue management ($n = 200$)

S. No.	Constraint	No. of respondents	Mean Garrett score	Rank
1	High cost of CRM machinery	168	72.84	I
2	Non-availability of machinery at the required time	156	69.76	II
3	Lack of awareness about improved CRM practices	149	65.43	III
4	High labour cost for residue management	142	62.18	IV

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S. No.	Constraint	No. of respondents	Mean Garrett score	Rank
5	Short time between harvesting and sowing of the next crop	137	59.72	V
6	Lack of custom hiring facilities for CRM machinery	126	56.85	VI
7	Difficulty in transportation and storage of crop residues	118	53.64	VII
8	Lack of technical guidance on residue management	105	50.92	VIII
9	Lack of market/use opportunities for collected crop residues	94	47.36	IX
10	Inadequate access to credit for CRM equipment	82	43.81	X

High cost of CRM machinery emerged as the first-ranked constraint (mean Garrett score 72.84), followed by non-availability of machinery at the required time (69.76) and lack of awareness about improved CRM practices (65.43). High labour cost (62.18) and the short interval between harvesting and sowing (59.72) were the next important constraints. Custom hiring limitations, transportation/storage difficulties, inadequate technical guidance, weak market or utilization opportunities for residue, and limited credit access occupied ranks VI to X, respectively.

High cost of CRM machinery (Rank I). The highest ranking of machinery cost suggests that the financial burden associated with residue-management equipment is a major concern. Machinery such as residue incorporators, straw management systems and seeders may involve substantial ownership or hiring costs. Choudhary *et al.* (2021) [11] similarly reported high production cost through hiring of machinery as the second most severe constraint in their Garrett-ranking study of farmers in Haryana. Their study also identified the limited time between crops as the leading constraint. Singh *et al.*, (2017) [12] similarly identified machinery and operating-window issues as important field constraints to Happy Seeder adoption.

Non-availability of machinery at the required time (Rank II). Timely access to machinery is critical because residue management has to be completed within a narrow window before the succeeding crop. Research on custom hiring services has repeatedly identified peak-season machinery availability as a major problem. Kisku *et al.* (2022) [13] found non-availability of machinery during the peak season to be a major constraint, while Ghanghas *et al.* (2024) [14] reported insufficient machinery during peak periods as a serious constraint among farmers using custom hiring centres in Haryana. The variation among adoption scores suggests that farmers may adopt practices differently according to their costs, machinery requirements and perceived benefits. Keil *et al.* (2021) [15] reported that Happy Seeder adoption can reduce wheat production costs while maintaining yields.

Lack of awareness about improved CRM practices (Rank III). The third rank indicates the importance of information and extension support. Farmers may require practical knowledge about suitable machinery, operating procedures, residue incorporation and alternative uses. Kisku *et al.* (2022) [13] reported lack of knowledge about custom hiring centres as the most frequently expressed constraint among their respondents, supporting the relevance of awareness and technical information.

High labour cost (Rank IV). Residue collection, transportation and handling can be labour-intensive when suitable machinery is unavailable. Increasing labour expenditure can therefore discourage farmers from labour-dependent residue-management methods and increase their preference for rapid mechanized solutions.

Short time between harvesting and sowing (Rank V). The narrow turnaround period between rice harvest and wheat sowing creates a strong operational constraint. More recent farmer-focused research in Punjab also describes the limited time available between rice harvest-

ing and wheat sowing as an important factor constraining no-burn residue management.

Lack of custom hiring facilities (Rank VI). When individual ownership of CRM machinery is costly, custom hiring can provide access without requiring farmers to purchase equipment. Consequently, inadequate local custom hiring infrastructure can limit access. Studies of custom hiring services have recommended increasing the number and accessibility of such centres to improve machinery access.

Transportation and storage difficulties (Rank VII). Crop residues are bulky and can be costly to collect, transport and store. Where there is no nearby utilization or marketing channel, farmers may perceive residue handling as an additional burden.

Lack of technical guidance (Rank VIII). CRM machinery and practices require appropriate selection, calibration and operation. Limited technical guidance can reduce farmers' confidence in adopting unfamiliar practices. Kisku *et al.* (2022) [13] identified dissemination of technical know-how as an important suggestion for overcoming machinery-related constraints.

Lack of market/use opportunities for collected residues (Rank IX). The absence of reliable outlets for collected straw can reduce its economic attractiveness. Evidence from Punjab indicates that farmers have expressed interest in greater utilization and market opportunities for residues, while local organizations can help improve access to no-burn technologies and information.

Inadequate access to credit for CRM equipment (Rank X). Limited credit can restrict investment in machinery, particularly where individual ownership is financially difficult. Although this constraint received the lowest illustrative rank in the present table, access to finance remains relevant because the affordability of CRM equipment and hiring services affects adoption decisions.

Overall, the constraint pattern indicates that CRM adoption is influenced by a combination of economic, technological, temporal and information-related factors. This pattern is broadly consistent with previous Indian studies. Choudhary *et al.* (2021) [11] found the short interval between crops, high machinery hiring cost and limited practical techniques among the leading constraints. Kisku *et al.* (2022) [13] reported lack of knowledge and peak-season machinery non-availability as prominent constraints.

Conclusion

Crop residue management is an important pathway for reducing residue burning and improving the sustainability of crop production systems. The proposed assessment among 200 respondents showed comparatively greater adoption of avoiding residue burning, timely residue management and residue incorporation, while collection/baling for ex-situ utilization showed comparatively lower adoption. Wider adoption of CRM practices requires a combination of awareness, practical demonstrations, timely technical advice, affordable machinery access and effective custom-hiring arrangements. For a final research manuscript, the illustrative frequencies in this paper

should be replaced with verified field observations from the 200 respondents.

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