



Economic and environmental impact of paddy residue management in Raebareli and adjoining districts of Central Uttar Pradesh: A farmer survey

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ABSTRACT

Paddy residue management remains a critical agricultural challenge in northern India, particularly in the rice-wheat cropping belt of Uttar Pradesh. This study examined the economic and environmental impacts of prevailing paddy residue management practices among farmers in Raebareli and adjoining districts through structured field interviews. A total of 31 farmers were surveyed at the Kisan Mela held in December 2024-January 2025 using a pre-validated questionnaire covering residue management methods, perceived economic benefits, soil health indicators, and environmental awareness. Results indicate that 41.9% of respondents use harvested straw as animal fodder, while 35.5% incorporate it into the soil. Approximately 90.3% of respondents reported a reduction in input costs, and 83.9% reported positive yield changes following adoption of scientific management methods. Environmental perception analysis revealed that 96.8% of farmers believe residue management can mitigate climate change, and 77.4% observed water conservation benefits. Soil quality improvement was perceived by 77.4% of respondents. Barriers to adoption included limited access to machinery, inadequate technical training, and absence of market linkages for residue-based products. Given the exploratory nature of this cross-sectional survey ($n=31$), findings are indicative and a larger representative survey is recommended for confirmatory analysis.

Keywords: Paddy residue management, Soil health, Uttar Pradesh, In-situ management, PUSA decomposer, Rice-wheat system

INTRODUCTION

India is an agrarian economy where approximately 70% of the population depends on agriculture for livelihood (Pathak *et al.*, 2012). The Green Revolution substantially increased food grain production, and with it, the volume of crop residue generated annually. India produces approximately 500 million tonnes of crop residue per year, of which Uttar Pradesh alone contributes nearly 60 million tonnes - the highest of any state (MNRE, n.d.). Rice accounts for approximately 48% of total residue production, followed by wheat at 32% (ICAR, 2020).

In Raebareli and adjoining districts of Uttar Pradesh, the rice-wheat cropping system is

predominant. Following mechanical combine harvesting, a large volume of paddy straw remains in the field, and farmers typically have a window of only 20-25 days before the next wheat sowing cycle. This time constraint, combined with high labour costs and limited alternatives, has historically driven farmers to burn crop residue in the field - a practice that generates greenhouse gases, deteriorates soil biological activity, and creates serious public health hazards through particulate matter ($PM_{2.5}$ and PM_{10}) emissions (Lan *et al.*, 2022).

Scientific residue management practices - including in-situ decomposition using bio decomposer, vermicomposting, biochar production,

silage making, and no-till seeding through Happy Seeder or turbo-seeder - offer economically and environmentally superior alternatives. Microbial decomposer “Halo-CRD” developed by ICAR-CSSRI is also reported to be effective in-situ crop residue decomposition (Kumar *et al.*, 2025a). Several government schemes, including the PM KUSUM Yojana, Harit Krishi Yojana, and the National Bio-Energy Mission, aim to incentivise adoption of these practices. However, on-ground uptake remains limited due to knowledge gaps, infrastructural constraints, and market failures.

Research Objectives

This study was undertaken with the following specific objectives:

1. To document the prevailing paddy residue management practices adopted by farmers in Raebareli and adjoining districts, Uttar Pradesh.
2. To assess the perceived economic impact of different residue management methods, including changes in input cost, crop yield, and supplementary income generation.
3. To evaluate farmers’ perception of the environmental impact on soil health, water conservation, and climate change mitigation.
4. To identify the key barriers and motivating factors that influence adoption of scientific residue management practices.
5. To suggest policy and extension-level interventions for scaling sustainable residue management in the rice–wheat belt of Uttar Pradesh.

Research Propositions

P₁ (Economic): Adoption of scientific paddy residue management practices (in-situ incorporation, composting, or PUSA decomposer application) is associated with perceived reduction in input costs and improved crop yields among farmers in Raebareli and adjoining districts.

P₂ (Environmental): Scientific residue management practices are positively associated with improved soil quality, water retention, and reduced greenhouse gas emissions, as perceived by farmers.

P₃ (Adoption): Financial incentives and access to technical training are the primary enabling factors for adoption of sustainable residue management practices among smallholder farmers in Raebareli and adjoining districts.

Research Gap

While substantial literature exists on paddy residue management in Punjab and Haryana, studies specifically examining the economic and environmental dimensions of residue management in the central Uttar Pradesh belt - particularly Raebareli and adjoining districts - remain limited. Existing studies have focused predominantly on agronomic outcomes of in situ management (Pathak *et al.*, 2012; Jain *et al.*, 2014; Yadav and Arora, 2018) or on air quality impacts of field burning (Jain *et al.*, 2014; Lan *et al.*, 2022), without integrating farmer-level economic perception, environmental awareness, and adoption barriers in a single framework. The present study addresses this gap through a primary survey approach combining structured interviews and field observation.

Scale and Significance of Crop Residue Generation in India

India generates approximately 500 million tonnes of crop residue annually (Pathak *et al.*, 2012). The Harvest Index (HI) of high-yielding varieties (HYVs) typically ranges from 0.40 to 0.50, meaning that for every kilogramme of grain produced, 1.0-1.5 kg of biomass remain in the field (Kaur and Singh, 2024). Uttar Pradesh contributes approximately 60 million tonnes annually - the highest share of any state (IRRI, n.d.). The time window between paddy harvesting and optimal wheat sowing is approximately 15-25 days, creating acute time pressure on farmers (Pathak *et al.*, 2012).

Rice straw contains approximately 10-15% silica and has a high C:N ratio, making it resistant to natural decomposition; under field conditions, natural decomposition of rice straw may require two to three months - a timeframe unavailable to farmers in the rice-wheat belt (Kaur and Singh, 2024).

Traditional and Scientific Residue Management Methods

Paddy residue management practices can be broadly classified into traditional (low-technology) and scientific (technology-assisted) methods. Traditional methods can absorb only an estimated 10-15% of the total residue volume generated at the national scale (Pathak *et al.*, 2012). Microbial consortia for rice-wheat straw decomposition under incubation study resulted in build up of soil C and improved soil enzymatic activity (Rani *et al.*, 2024).

The PUSA decomposer, a fungal consortia developed by ICAR-IARI, accelerates lignin degradation in paddy straw, enabling decomposition within 20-25 days under field conditions - a timeframe compatible with the rice-wheat sowing window (ICAR, 2020; Lamba and Gill, 2024). The Happy Seeder integrates a stub cutter with a zero-till drill, enabling it to simultaneously cut and lift standing paddy stubble, sow wheat seed, and redistribute cut straw as a surface mulch layer - all in a single pass (Singh *et al.*, 2021). Ex-situ management approaches include vermicomposting, biogas/bio-CNG production, mushroom cultivation (*Volvariella volvacea*), and silage production (Kaur and Singh, 2024; NDDDB, 2024).

Economic Implications of Paddy Residue Management

When one tonne of paddy straw is burned, losses include approximately 5.5 kg nitrogen, 2.3 kg phosphorus, 25 kg potassium, and 1.2 kg sulphur - a fertiliser-equivalent loss of Rs. 4,000-5,000 per tonne (Pathak *et al.*, 2012; ICAR, 2020). Kumar *et al.* (2025b) evaluated use of paddy straw decomposition using bio-decomposer Halo-CRD and found to be economically feasible for production of wheat. Scientific residue management enables reductions of approximately 15-20% in chemical fertiliser requirements over 3-4 seasons, 20-25% savings in irrigation water, and net operational savings of Rs. 2,000-3,000 per hectare under Happy Seeder operation (ICAR, 2020; Kaur *et al.*, 2023).

Environmental Impact of Residue Burning

Open-field burning of paddy straw generates PM_{2.5} and PM₁₀ particulate matter, with PM_{2.5} causally associated with severe asthma, COPD, lung cancer, and cardiovascular disease (Biswal *et al.*, 2025). Combustion of one tonne of paddy straw releases approximately 1.46 tonnes of CO₂, together with CH₄ (28 times the global warming potential of CO₂) and N₂O (265-298 times more potent) (Jain *et al.*, 2014). Soil surface temperatures during field burning rise to 50-70°C, with peaks of up to 150°C in the top 3-5 cm, destroying populations of nitrogen-fixing bacteria (*Rhizobium*, *Azotobacter*) and mycorrhizal fungi; microbial populations may decline by up to 50% immediately following burning (Das *et al.*, 2025).

The National Green Tribunal (NGT) imposed a complete ban on residue burning in Uttar Pradesh,

Punjab, Rajasthan, and Haryana (2015), establishing graduated environmental compensation: Rs. 2,500 for smallholders (<2 acres), Rs. 5,000 for medium holders (2-5 acres), and Rs. 15,000 for large holders (>5 acres) (Bhuvaneshwari and Hettiarachchi, 2019).

Effect of Residue Management on Soil Health

Soil organic carbon (SOC) is the single most important determinant of soil health. In many intensively cultivated areas of central Uttar Pradesh, SOC levels have been recorded as low as 0.3% - well below the agronomically desirable threshold of 0.5-0.75% (Das *et al.*, 2025). Das *et al.* (2025), drawing on 33 years of long-term field experiment data from Uttar Pradesh, provide robust multi-decadal validation that continuous residue retention significantly increases SOC stabilisation rates in the 0-15 cm topsoil layer. Ravish *et al.* (2025) demonstrated that residue-managed fields exhibit significantly lower evaporative water loss, translating into reduced irrigation costs for farmers in water-stressed districts. Improvement in soil properties with significant build-up of soil C with in-situ decomposition of paddy residue in sodic soil compared to burning (Maurya *et al.*, 2026).

Government Policy and Schemes for Residue Management

The Sub-Mission on Agricultural Mechanisation (SMAM) provides subsidies of up to 80% for establishment of Custom Hiring Centres (CHCs) equipped with Happy Seeders, Super Seeders, and straw balers; individual farmers receive up to 50% subsidy on direct machinery purchase (PIB, 2024). Under the GOBARdhan scheme, paddy straw is co-digested with cattle dung in Compressed Bio-Gas (CBG) plants; Uttar Pradesh had 37 functional commercial CBG plants and 114 community-level plants operational as of early 2026 (PIB, 2024).

Farmer Awareness and Adoption Barriers

A well-documented paradox is that farmer awareness of the consequences of residue burning does not automatically translate into behavioural change (Raza *et al.*, 2019). Raza *et al.* (2019) demonstrated through structural equation modelling that subjective norms, perceived behavioural control, and economic feasibility - not awareness alone - are the dominant determinants of sustainable residue management adoption intentions. Bhatt *et al.* (2023)

demonstrated that trust in extension agencies, access to equipment, and market linkages are the three factors most strongly predictive of willingness to abandon burning.

MATERIALS AND METHODS

Study Area

The study was conducted in Raebareli and adjoining districts, Uttar Pradesh (26.23°N, 81.24°E), a predominantly agricultural district in the central Gangetic plain. The rice-wheat cropping system is predominant, with paddy production of approximately 1 million tonnes per annum.

Data Collection

Primary data were collected through structured personal interviews with farmers at the Kisan Mela (Farmer Fair) held on 23 December 2024 and 8-10 January 2025 in Raebareli and adjoining districts. A pre-structured questionnaire comprising 28 items was administered across five thematic sections: (i) farmer socio-demographic profile, (ii) residue management practices, (iii) economic impact, (iv) environmental impact and sustainability, and (v) perceptions and future plans.

Questionnaire Validation: The questionnaire was developed in consultation with subject-matter specialists in agricultural science and environmental studies. A pilot test was conducted with five farmers prior to the main data collection to ensure clarity and relevance of items.

A total of 33 responses were received; two respondents from districts outside the central Uttar Pradesh rice-wheat agro-ecological zone (Mirzapur and Kanpur) were excluded from analysis, yielding a final analytical sample of $n=31$.

Operational Definition: Scientific Residue Management: For the purposes of this study, “scientific residue management” refers to practices adopted as alternatives to open-field burning, comprising: (a) in-situ biological decomposition using PUSA decomposer (fungal consortia); (b) soil incorporation using rotavator/super-seeder; (c) zero-tillage sowing via Happy Seeder; and (d) ex-situ utilisation for biogas, vermicompost, or animal fodder. Traditional practices include use of straw as animal fodder, sale, or natural decomposition without active management.

Data Analysis

Responses were tabulated and analysed using descriptive statistics including frequency distribution and percentage analysis. All percentages are calculated with reference to the full analytical sample ($n=31$). Qualitative responses were categorised thematically. All analyses were performed using Microsoft Excel. Given the exploratory and cross-sectional nature of the survey, inferential statistics were not applied; results are presented as frequency tables.

RESULTS

Socio-demographic Profile of Respondents

Table 1 presents the socio-demographic characteristics of the 31 surveyed farmers. The majority of respondents fell in the 18-30 and 41-50 age brackets (32.3% each). Males constituted 71.0% of respondents, reflecting prevailing gender patterns in field-level agricultural decision-making. A notable 38.7% of respondents had graduate-level or higher education, which may partially explain their awareness of environmental consequences of residue burning. All respondents (100%) practised the rice-wheat cropping system, consistent with the dominant agricultural pattern of the district.

Table 1. Socio-demographic profile of surveyed farmers, Raebareli and adjoining districts, UP ($n=31$)

Characteristic	Category	Frequency (<i>n</i>)	Percentage (%)
Age group (years)	18-30	10	32.3
	31-40	4	12.9
	41-50	10	32.3
	51-60	5	16.1
	>60	2	6.5
Gender	Male	22	71.0
	Female	9	29.0
Education level	Illiterate	2	6.5
	Primary	7	22.6
	Secondary	5	16.1
	Higher secondary	5	16.1
Cropping system	Graduate or above	12	38.7
	Rice-Wheat	31	100.0

Note: Data collected through structured interviews and Google Form survey at Kisan Mela, Raebareli and adjoining districts, December 2024-January 2025. Final analytical sample $n=31$ after exclusion of two respondents from outside the central UP agro-ecological zone.

Table 2. Paddy residue management practices and reasons for adoption ($n=31$)

Practice / Reason	Frequency (n)	Percentage (%)
A. Primary residue management method		
Animal fodder	13	41.9
Soil incorporation	11	35.5
Open-field burning	3	9.7
PUSA decomposer treatment	3	9.7
B. Reason for adoption		
Environmental concern	19	61.3
Cost saving	10	32.3
Community/peer influence	2	6.5
C. Duration of current practice		
<1 year	4	12.9
1–2 years	3	9.7
3–5 years	11	35.5
>5 years	16	51.6

Paddy Residue Management Practices

Table 2 summarises the residue management practices adopted by respondents. The most common practice was using straw as animal fodder (41.9%), followed by soil incorporation (35.5%), PUSA decomposer treatment (9.7%), and open-field burning (9.7%). Notably, among the 9.7% of respondents who mentioned burning, none identified it as their primary management strategy - this may reflect awareness bias within the Kisan Mela setting. A majority (51.6%) had practised their current method for more than five years. Environmental concern was the primary motivating factor for 61.3% of respondents.

Table 3. Perceived economic impact of paddy residue management ($n=31$)

Indicator	Response	Freq. (n)	%
Input cost reduction after adoption	Yes	28	90.3
	Uncertain	3	9.7
	<10%	5	16.1
Estimated cost reduction (among adopters, $n=28$)	10-20%	10	32.3
	20-30%	11	35.5
	>30%	2	6.5
Change in crop yield	Positive	26	83.9
	No change	5	16.1
Additional income from residue products	Yes	10	32.3
	No	21	67.7
Annual additional income - if yes ($n=10$)	< Rs. 5,000	10	100.0

Perceived Economic Impact

Table 3 presents the perceived economic impacts of residue management. A substantial majority (90.3%) reported a reduction in input costs following adoption of scientific residue management, while 9.7% were uncertain. Among those reporting cost reductions ($n=28$), the magnitude was distributed across four brackets: <10% (16.1%), 10–20% (32.3%), 20-30% (35.5%), and >30% (6.5%). Similarly, 83.9% reported a positive change in crop yield, while 16.1% reported no change. Additional income from residue-based products was reported by 32.3% of respondents, all of whom reported annual income below Rs. 5,000, indicating the nascent stage of residue value-addition in the study area.

Environmental Impact and Sustainability

Table 4 summarises farmers' perceptions of environmental impacts. A majority of respondents (77.4%) perceived improvement in soil quality following residue management. Soil health was broadly perceived as positively affected by 93.5% of farmers. Water conservation benefits were reported by 77.4% of respondents. Most strikingly, 96.8% of respondents believed that residue management contributes to climate change mitigation - a finding that underscores growing environmental awareness, likely facilitated by government extension programmes and media outreach. A fungal consortia Halo-CaRe developed for effective in-situ and ex-situ decomposition of paddy and sugarcane residues and recycling soil organic C and other properties (Arora *et al.*, 2024).

Table 4. Farmers' perception of environmental impact of residue management ($n=31$)

Environmental Indicator	Response	Freq. (n)	%
Perceived change in soil quality	Improved	24	77.4
	No change	4	12.9
	Degraded	3	9.7
Soil health positively affected	Yes	29	93.5
	Uncertain	2	6.5
Water conservation observed	Yes	24	77.4
	No	4	12.9
	Uncertain	3	9.7
Aids climate change mitigation	Yes	30	96.8
	Uncertain	1	3.2
	No	0	0.0

Table 5. Factors perceived to motivate wider adoption of residue management ($n=31$)

Motivating Factor	Frequency (n)	Percentage (%)
Technical training and knowledge dissemination	19	61.3
Market linkage for residue-based products	13	41.9
Financial incentives / government subsidies	11	35.5
Availability of machinery and equipment	8	25.8

Motivating Factors for Wider Adoption

Table 5 presents farmer-perceived motivating factors for broader adoption of residue management practices. Technical training and knowledge dissemination was identified as the most important motivating factor (61.3%), followed by market linkage for residue-based products (41.9%), financial incentives and government subsidies (35.5%), and availability of machinery and equipment (25.8%).

DISCUSSION

The findings of this study are consistent with the broader literature on paddy residue management in northern India. The dominance of animal fodder use (41.9%) as the primary residue management strategy aligns with observations from other rice–wheat belt regions (Jain *et al.*, 2014). Kaur and Singh (2024) similarly documented animal fodder as the predominant traditional residue utilisation method across Northern India. The growing shift toward in-situ management (35.5% practising soil incorporation) aligns with adoption trends reported by Singh *et al.*, (2020) and Singh and Kaur (2023) in Punjab.

The high proportion of respondents (90.3%) reporting input cost reduction and the 83.9% reporting positive yield impact following adoption of scientific management methods aligns with findings from ICAR studies demonstrating that in-situ incorporation of residue - particularly when treated with PUSA decomposer - improves soil organic carbon, microbial biomass, and long-term fertility (ICAR, 2020). Arora *et al.* (2021) proposed Halo-CRD as bacterial decomposer for faster in-situ decomposition and improve soil health. Das *et al.* (2025), drawing on 33 years of long-term field experiment data from Uttar Pradesh, provided robust evidence that integrated organic management including paddy straw incorporation substantially increases soil organic carbon accrual.

The high environmental awareness among respondents (96.8% acknowledging climate change

mitigation potential) reflects the impact of government extension activities and Kisan Mela outreach programmes. However, awareness alone does not translate to adoption. Raza *et al.*, (2019) demonstrated through structural equation modelling that subjective norms, perceived behavioural control, and financial constraints collectively shape farmers' intentions toward sustainable residue management. Singh *et al.* (2023) assessed the farmers perception for climate resilient interventions in Hardoi and reported that they are aware and intend to adopt feasible crop and soil management to tackle climate adversities. The identification of technical training (61.3%) and market linkage (41.9%) as primary motivating factors is consistent with findings of Bhatt *et al.*, (2023), who reported that trust in extension agencies, awareness of alternatives, and access to equipment are the three principal barriers to adoption in Northern India.

The sample size in this study ($n = 31$) is a recognised limitation. The findings should be interpreted as preliminary and exploratory, reflecting conditions at the Kisan Mela setting where participants are likely more aware of sustainable practices than the general farmer population. Kaur and Kumari (2025) highlight that larger representative samples reveal greater heterogeneity in adoption barriers than smaller convenience samples. A larger, randomly sampled survey across multiple villages is therefore recommended for confirmatory analysis and policy-level generalisation.

CONCLUSION

This study assessed the economic and environmental impacts of paddy residue management practices in Raebareli and adjoining districts, Uttar Pradesh, through structured farmer interviews ($n=31$). The key findings are:

1. Animal fodder remains the dominant residue management practice (41.9%), reflecting the importance of straw as a livestock input in the rice–wheat belt.

2. 90.3% of farmers reported input cost reduction and 83.9% reported positive yield change following adoption of scientific residue management methods.
3. Farmers broadly perceived positive environmental outcomes, with 96.8% acknowledging the climate change mitigation potential of sustainable residue management.
4. Technical training (61.3%), market linkage (41.9%), and financial incentives (35.5%) were identified as the three most critical enabling factors for wider adoption.
5. Residue burning, while not the primary practice among surveyed farmers, remains a systemic challenge driven by time constraints, labour costs, and limited access to alternative options.

Government initiatives such as PM KUSUM Yojana, Harit Krishi Yojana, and the National Bio-Energy Mission provide a supportive policy framework. Integrating mandatory post-harvest decomposer application with combine harvester usage, combined with village-level training camps and market development for residue-based products, could substantially reduce open-field burning and convert residue from a waste problem into a renewable resource.

Limitations of the Study

Small sample size ($n=31$): The study is exploratory in nature and findings cannot be statistically generalised without a larger, representative sample. A future study with $n \geq 100$ using random sampling is recommended.

Purposive sampling bias: Respondents were recruited at a Kisan Mela, where participants are likely more informed about sustainable agricultural practices than the general farmer population, potentially overestimating awareness and adoption rates.

Self-reported perception data: All economic and environmental outcomes are based on farmer perception rather than objective measurements such as soil chemical analysis, yield records, or remote sensing data.

Cross-sectional design: Data were collected at a single point in time and therefore cannot establish causal relationships between residue management practices and their reported outcomes.

Longitudinal designs would strengthen causal inference.

Geographic scope: The study is confined to Raebareli and adjoining districts and may not reflect conditions in other rice–wheat belt districts of Uttar Pradesh or other states with similar cropping systems.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper. No funding was received from any commercial, government, or non-governmental organisation that could have influenced the design, conduct, or reporting of this study.

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