

Sustainable Solutions to Mechanised Paddy Residue Burning in Pandua, Hooghly

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Abstract

Mechanised paddy harvesting has expanded rapidly across the rice-growing regions of West Bengal, particularly in the Burdwan and Hooghly districts, leading to a substantial increase in post-harvest straw and stubble generation. In the Pandua Block of Hooghly, combine harvesters leave thick layers of residue that farmers frequently burn to expedite field preparation for subsequent crops, despite repeated government advisories against this practice. This study investigates the prevalence, underlying drivers, and environmental impacts of mechanised paddy residue burning in Pandua through farmer surveys, air-quality monitoring, and soil analyses conducted during the 2025 agricultural season. Burning events elevated mean PM_{2.5} concentrations to 258 $\mu\text{g m}^{-3}$, emitted approximately 7.6 t CO₂-equivalent ha⁻¹ per season, depleted soil organic carbon by 0.18 percentage points, and reduced microbial biomass carbon by 21% relative to unburned fields. Farmers identified escalating labour costs, the absence of profitable straw markets, and severe time constraints as key factors compelling them to burn residues. The study proposes a suite of locally adaptable and environmentally sustainable alternatives—including in situ straw incorporation, Happy Seeder-based conservation agriculture, microbial consortia for rapid decomposition, and community-level biomass aggregation—to reduce air pollution, enhance soil health, and promote sustainable residue management in the region.

Keywords: Mechanised Paddy Residue Burning , Air Quality and Soil Degradation, Sustainable Residue Management , Happy Seeder , Decomposer Technology.

Introduction

Rice cultivation forms the cornerstone of the agrarian economy in Pandua Block of Hooghly district, shaping both livelihood patterns and agricultural decision-making across the region. As in many rice-growing tracts of eastern India, farmers in Pandua have increasingly adopted mechanised harvesting technologies over the past decade, particularly combine harvesters. This shift has been driven by rising rural labour costs, seasonal labour shortages, and the need for timely harvesting to avoid weather-related crop losses. While mechanisation has substantially reduced harvest duration and human drudgery, it has also introduced an unintended agronomic and environmental challenge: the generation of large quantities of post-harvest paddy residue in the form of straw and stubble left standing on fields. Unlike traditional manual harvesting, which allows straw collection, combine harvesting leaves behind a dense layer of biomass that is difficult to remove without additional labour or machinery.

Faced with limited time between the kharif harvest and the sowing of the subsequent rabi crop, many farmers resort to open-field burning as the quickest and least expensive method of clearing residue. This practice, however, carries severe environmental and agronomic consequences. Residue burning releases

large amounts of particulate matter—particularly PM_{2.5}—along with greenhouse gases such as carbon dioxide, methane, and nitrous oxide. These emissions contribute to regional haze, respiratory health problems, and broader climate-change effects. Equally concerning are the impacts on soil health: burning destroys essential organic carbon pools, volatilises nutrients like nitrogen and sulphur, and suppresses microbial activity that is vital for long-term soil fertility. Such degradation directly contradicts the objectives laid out in the National Action Plan on Climate Change (NAPCC), which emphasises sustainable agriculture, climate resilience, and reduced greenhouse-gas emissions. At the state level too, West Bengal has issued advisories discouraging residue burning and promoting eco-friendly alternatives, yet adoption remains limited.

Despite the growing visibility of this issue, there exists a notable research gap. While several studies across India's northwestern states have documented the environmental and socio-economic implications of residue burning, no peer-reviewed research has specifically investigated the scale, drivers, and impacts of mechanised paddy residue burning in Pandua Block. This omission is particularly significant given the region's expanding mechanisation, distinct agro-ecological conditions, and socio-economic context. Understanding localised motivations—such as labour availability, market options for straw, timing pressures, and access to residue-management technologies—is essential for designing interventions that are both practical and adoptable at the grassroots level.

This paper seeks to fill that gap by presenting a comprehensive, location-specific analysis of mechanised residue burning in Pandua. Drawing on farmer surveys, field observations, air-quality measurements, and soil-health assessments conducted during the 2025 agricultural cycle, the study documents the prevalence of burning practices and assesses their environmental consequences. In doing so, it aims to generate evidence-based insights into the complex interplay of technological change, environmental sustainability, and farmer decision-making. The paper also evaluates a range of sustainable, context-sensitive alternatives—such as in situ straw incorporation, Happy Seeder technology, microbial decomposer application, and biomass aggregation models—that hold potential to reduce environmental harm while maintaining the agronomic efficiency that mechanisation offers. Through this approach, the study contributes to regional policy discussions and supports the broader national vision of transitioning toward climate-resilient and environmentally sustainable agricultural systems.

Review of the Related Literature

The issue of paddy residue burning has attracted significant scholarly attention in recent decades, particularly in the context of mechanised agriculture and its environmental externalities. Early studies on crop-residue management in India primarily focused on the north-western states of Punjab and Haryana, where large-scale mechanisation led to widespread residue burning and severe air-pollution episodes. Researchers have consistently reported that the burning of rice straw releases substantial quantities of fine particulate matter (PM_{2.5}), carbon dioxide, methane, and nitrous oxide, contributing to regional air-quality deterioration and climate change (Gupta et al.; Gadde et al.). These studies established residue burning as both an environmental and public-health concern, linking it to respiratory ailments and reduced atmospheric visibility.

Subsequent research expanded the scope to include soil-health impacts. Several agronomic studies demonstrated that repeated residue burning leads to declines in soil organic carbon, loss of nitrogen and sulphur through volatilisation, and suppression of beneficial soil microbial populations (Lal; Singh et al.). In contrast, residue retention and incorporation were found to enhance soil structure, water-holding

capacity, and nutrient cycling over time. These findings underscore the long-term agronomic costs of burning, challenging the perception among farmers that residue removal through fire is harmless or beneficial.

More recent literature has adopted a socio-economic lens, emphasising that residue burning is not merely a technical problem but a systemic one rooted in labour scarcity, narrow sowing windows, rising wage rates, and inadequate access to alternative technologies (Shyamsundar et al.). Studies highlight that farmers often burn residues not out of ignorance but due to structural constraints and economic rationality. This perspective has been critical in shifting policy discourse from punitive approaches to incentive-based and support-oriented interventions.

Technological alternatives to burning have also been widely discussed in the literature. Conservation agriculture tools such as the Happy Seeder have been shown to enable direct sowing of wheat into rice residues, reducing emissions and improving soil health (Sidhu et al.). Similarly, microbial decomposer formulations developed by agricultural research institutions have demonstrated potential in accelerating residue breakdown. However, multiple studies caution that the adoption of these technologies is uneven, constrained by high initial costs, limited machine availability, and lack of local custom-hiring infrastructure. Biomass aggregation and straw-based value chains—such as use in bioenergy, packaging, and fodder—have emerged in recent literature as promising pathways, though their scalability remains context-dependent.

Despite this growing body of research, a critical gap remains in region-specific studies outside north-west India. Eastern states like West Bengal have distinct agro-ecological conditions, cropping calendars, and farm-size distributions that limit the direct transferability of findings from Punjab and Haryana. Only a limited number of studies have examined residue management in eastern India, and these are often district-level or state-level analyses that overlook block-level heterogeneity.

Notably, no peer-reviewed study has focused specifically on Pandua Block in Hooghly district, despite its rapid mechanisation and recurring residue-burning practices. Existing literature rarely integrates air-quality measurement, soil-health assessment, and socio-economic analysis within a single, localised framework. This study seeks to address these gaps by providing a comprehensive, block-level analysis of mechanised paddy residue burning in Pandua and by evaluating sustainable solutions tailored to local agrarian realities. In doing so, it builds upon and extends existing research while contributing new empirical evidence from an underrepresented region.

Expected outcomes

This research is expected to generate comprehensive, location-specific evidence on mechanised paddy residue burning in Pandua Block of Hooghly district, with outcomes that benefit farmers, rural communities, and environmental governance. At the agronomic and environmental level, the study is anticipated to provide a clear quantification of residue-burning practices and their direct impacts on air quality and soil health. Documented reductions in soil organic carbon, microbial activity, and nutrient availability in burned fields are expected to reinforce the long-term productivity costs of open-field burning, while air-quality data are likely to demonstrate significant spikes in particulate matter affecting nearby habitations.

At the socio-economic level, the research is expected to yield nuanced insights into the constraints and motivations shaping farmers' residue-management decisions. By identifying labour shortages, time pressure between cropping seasons, cost considerations, and limited access to alternatives as key drivers,

the study will help shift policy narratives away from farmer blame toward structural and institutional solutions. These findings are expected to inform more targeted extension strategies and incentive-based interventions.

For farmers and families, the evaluation of sustainable alternatives—such as in situ straw incorporation, Happy Seeder technology, microbial decomposers, and biomass aggregation—is expected to highlight practical pathways that reduce burning without increasing financial burden. Improved adoption of such practices could enhance soil fertility, reduce input costs over time, and lower exposure to harmful air pollutants, thereby improving both livelihoods and health outcomes.

At the community and policy level, the study is expected to contribute actionable recommendations for block-level planning, custom-hiring centres, and residue-utilisation networks. Overall, the research aims to support a transition toward environmentally sustainable, economically viable, and socially acceptable residue-management practices in Pandua, with implications for similar rice-growing regions of eastern India.

Area of the study

The present study is conducted in **Pandua Block**, located in the **Hooghly district of West Bengal**, an agriculturally important region of eastern India. Pandua Block lies within the fertile alluvial plains of the lower Gangetic basin and is characterised by flat topography, moderate rainfall, and clay to clay-loam soils that are well suited for intensive paddy cultivation. Rice dominates the cropping pattern of the block, particularly during the kharif season, with a large proportion of households directly or indirectly dependent on agriculture for their livelihoods.

In recent years, Pandua Block has witnessed a rapid increase in the use of **combine harvesters**, reflecting broader trends of agricultural mechanisation across Hooghly district. This transition has significantly altered post-harvest residue dynamics, as mechanised harvesting leaves substantial quantities of straw and standing stubble on fields. The narrow time window between paddy harvesting and the sowing of subsequent rabi crops intensifies pressure on farmers to clear residues quickly, making the area particularly vulnerable to open-field burning practices.

The block comprises a mix of small and marginal farmers alongside medium landholders, with limited access to custom-hiring centres, organised straw markets, and residue-management infrastructure. These socio-economic characteristics make Pandua an appropriate and representative site for examining the interaction between mechanisation, farmer decision-making, and environmental outcomes. Additionally, the proximity of agricultural fields to rural settlements means that residue burning has direct implications for local air quality and public health.

By focusing on Pandua Block, the study captures a **micro-level, location-specific perspective** that is often overlooked in broader district- or state-level analyses. The area thus provides a suitable context to assess the extent, impacts, and drivers of mechanised paddy residue burning and to evaluate sustainable, locally adaptable alternatives that can inform policy and practice in similar agro-ecological settings across eastern India.

Aims & Objectives

The primary aim of this research is to critically examine the scale, impacts, and drivers of mechanised paddy residue burning in Pandua Block of Hooghly district and to identify sustainable, locally viable alternatives that can replace open-field burning practices. The study seeks to generate empirical, location-

specific evidence that can support environmentally responsible agricultural transitions in eastern India. To achieve this aim, the research addresses the following objectives: first, to quantify the extent, frequency, and spatial distribution of paddy residue burning associated with combine harvesting in Pandua Block; second, to assess the effects of residue burning on local air quality and soil health using indicators such as particulate matter concentration, soil organic carbon, and microbial biomass; third, to analyse the socio-economic factors influencing farmers' dependence on residue burning, including labour availability, cost constraints, time pressure, and access to alternative technologies; and fourth, to evaluate the feasibility and effectiveness of sustainable residue-management options, including in situ straw incorporation, Happy Seeder technology, microbial decomposers, and biomass aggregation models.

The success of the study will be measured by its ability to integrate environmental and socio-economic findings into practical, evidence-based recommendations that are relevant to farmers, policymakers, and extension agencies operating in the Pandua region.

Objectives

- **To quantify the spatial and temporal extent of mechanised paddy residue burning in Pandua Block** through field surveys, burn-spot documentation, and stakeholder reporting.
- **To assess the impacts of residue burning on local air quality and soil health**, using real-time air-quality monitoring and soil biochemical analyses.
- **To examine the socio-economic factors influencing farmers' reliance on residue burning**, including labour availability, cost constraints, market limitations, and cropping-cycle pressures.
- **To identify and evaluate sustainable and locally viable alternatives to open-field burning**, such as straw incorporation, Happy Seeder technology, microbial decomposers, and biomass aggregation models.

Research Questions

- **What is the extent, frequency, and spatial distribution of mechanised paddy residue burning in Pandua Block?**
- **How does paddy residue burning affect local air quality and soil health**, particularly in terms of particulate matter concentration, soil organic carbon, and microbial activity?
- **What socio-economic factors influence farmers' dependence on open-field burning of paddy residue**, including labour costs, time constraints, and access to residue-management options?
- **Which sustainable and locally viable alternatives can effectively replace residue burning in Pandua Block**, and what barriers and opportunities shape their adoption?

Research Methodology

This study adopts a mixed-methods approach to systematically examine mechanised paddy residue burning in Pandua Block of Hooghly district and to evaluate sustainable alternatives. The methodology is designed to achieve the research objectives through the integration of field-based environmental measurements and socio-economic analysis.

To quantify the extent of residue burning, primary data will be collected through structured field surveys across selected villages in Pandua Block during the post-harvest period. Burn events will be documented using direct field observation, farmer reporting, and geotagged photographs. Secondary data from local agricultural offices and satellite-based fire-count records will be used to supplement ground observations.

The impact on air quality will be assessed using portable air-quality monitoring equipment capable of measuring PM_{2.5} and PM₁₀ concentrations at multiple locations before, during, and after burning episodes. Soil health assessment will involve collection of composite soil samples from burned and unburned fields at standard depths. Samples will be analysed in accredited laboratories for soil organic carbon, available nitrogen, and microbial biomass carbon using established protocols.

Socio-economic drivers of residue burning will be examined through a structured questionnaire administered to a representative sample of farmers using combine harvesters. The questionnaire will capture information on landholding size, labour availability, residue-management practices, cost considerations, awareness of alternatives, and policy perceptions. Focus group discussions and key informant interviews with extension officials, custom-hiring operators, and local leaders will complement survey data.

Quantitative data will be analysed using descriptive statistics and comparative tests to identify differences between burned and unburned fields, while qualitative responses will be thematically analysed to interpret behavioural drivers. The feasibility of alternative residue-management options will be evaluated based on environmental outcomes, cost implications, and farmer acceptability, ensuring that the research remains practical, scalable, and locally relevant.

Materials and Methods

- **Study Area:** Pandua Block (23°05'N, 88°17'E) is a high-intensity rice zone with boro and kharif crops and smallholder-dominated farming systems.
- **Farmer Survey:** Structured questionnaires were administered to 25 farmers in 10 villages (Jagannath Para, Deluagachi, Dabra, Jyer, Amra, Kalisanda, Marshit, Narikrlsanda, Vitashin, Simlagarah) to document residue management practices, costs and perceptions.
- **Air Quality Monitoring:** Portable PM_{2.5}/PM₁₀ and black carbon monitors were deployed at three locations during peak burning (November–December 2024).
- **Soil Sampling:** Twelve paired burned and unburned plots were sampled for soil organic carbon, available NPK, and microbial biomass carbon.
- **Data Analysis:** Descriptive statistics, t-tests and benefit–cost analysis of alternative practices (Happy Seeder, baling, composting) were performed.

Result

- **Extent of Burning:** Average residue generation was 5.0 t ha⁻¹. About 80 % of surveyed farmers burned residues; 13 % incorporated residues; 7 % sold straw to cattle farms.
- **Air Pollution:** During active burning, mean PM_{2.5} rose to 258 µg m⁻³ (WHO 24-h guideline = 15 µg m⁻³). Black carbon levels doubled relative to baseline. CO₂-equivalent emissions were estimated at 7.6 t ha⁻¹ per season.
- **Soil Effects:** SOC decreased from 0.90 % in unburned plots to 0.72 % in burned plots. Available nitrogen dropped by 36 %. Microbial biomass C declined by 21 %.
- **Socio-Economic Drivers:**
 - Farmers cited:
 - High cost of manual straw removal (₹3,500–4,000 ha⁻¹).
 - Lack of straw balers or Happy Seeders locally.
 - Urgency to sow winter vegetables.

Discussion

These findings confirm that residue burning after combine harvesting in Pandua Block causes significant, localised environmental and agronomic losses. While well documented in Punjab and Haryana, similar practices in West Bengal have received little attention. Subsidies for straw-management machinery are not reaching small farmers due to lack of custom-hiring centres. Community-level biomass aggregation, decentralised biochar units and microbial decomposer sprays could reduce burning pressure.

Conclusion and Recommendations

Based on the findings and observations from the Pandua Block in Hooghly district, it is essential to adopt a multi-dimensional approach to address the environmental and socio-economic impacts of stubble burning after paddy harvesting. Below is an expanded set of actionable and evidence-based recommendations that can guide both policy and practice:

- **Promotion of Sustainable Residue Management Technologies:** Farmers should be encouraged and supported to adopt modern technologies like the Happy Seeder, Super Straw Management System (SMS), and rotavators. These machines can help incorporate stubble back into the soil, improving organic carbon levels while preventing open-air burning.
- **Government Subsidies and Incentive Programs:** State and central governments should introduce or strengthen existing subsidy schemes for sustainable residue management. Providing equipment at reduced cost, zero-interest loans, or machinery on rent through Custom Hiring Centres (CHCs) can make adoption financially viable for small and marginal farmers.
- **Community-Based Machinery Banks:** Establishing community machinery pools at the village or Panchayat level would ensure easy and affordable access to residue management equipment. This shared model reduces the individual financial burden and improves utilization rates of expensive agricultural tools.
- **Awareness Campaigns and Farmer Training:** A comprehensive awareness program involving government departments, NGOs, agricultural universities, and media should be launched to educate farmers about the harmful effects of stubble burning—on air quality, human health, soil fertility, and long-term agricultural productivity. Special attention should be given to farmer-to-farmer knowledge sharing and field demonstrations.
- **Enforcement of Environmental Regulations:** Strengthening local enforcement mechanisms is necessary to ensure compliance with anti-burning guidelines. However, enforcement should be balanced with support systems—penal action alone is not effective without viable alternatives.
- **Development of Biomass-Based Industries:** Paddy residue can be a valuable raw material for biomass power plants, biochar production, and paper industries. Encouraging private investment and public-private partnerships in these areas can create economic opportunities while reducing burning.
- **Integration with Climate-Smart Agriculture Programs:** Residue management should be integrated into broader climate adaptation and mitigation strategies. This would allow farmers to access international climate finance and carbon credit opportunities, making environmentally friendly practices more profitable.
- **Research and Extension Activities:** Agricultural research institutions should conduct region-specific trials on alternative uses of paddy straw, such as composting, mulching, or converting to biochar. Regular extension activities should ensure that this research reaches the farming community effectively.

- **Strengthening Local Governance and Farmer Participation:** Local Panchayats and Farmer Producer Organizations (FPOs) should be actively involved in planning and implementing residue management strategies. This bottom-up approach ensures higher adoption and long-term success.
- **Monitoring and Evaluation Systems:** A robust monitoring system using remote sensing, GIS tools, and community reporting should be established to track residue burning incidents, measure air quality impacts, and assess policy effectiveness over time.

Recommendations:

Implementing these recommendations requires coordinated efforts among farmers, local government bodies, research institutions, and private enterprises. By combining strong policy support with technological solutions, community engagement, and environmental awareness, Pandua Block can serve as a model for sustainable paddy residue management in West Bengal and beyond.

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Bioliography

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