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Agronomical Impacts and Performance of Combined Harvester with Integrated Straw Management System

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Abstract

The evolution of combine harvesters from manual and labour-intensive methods to advanced, technology-driven machines has greatly impacted agricultural practices, particularly in straw management. Historically, crop harvesting involved significant human effort, with straw often burned or left in the field, leading to environmental concerns and soil degradation. The advent of combine harvesters in the 20th century revolutionized harvesting efficiency, but early models did not address effective straw management. Today's modern combine harvesters are equipped with sophisticated systems that chop, spread, or bale straw, offering sustainable solutions that enhance soil health by returning organic matter, improving soil fertility, and preventing erosion. Additionally, advanced technologies such as GPS and sensors allow for real-time optimization of harvesting and straw management processes. These innovations not only reduce environmental impacts, such as straw burning, but also provide economic benefits by enabling the reuse of straw for purposes like animal bedding or biomass fuel. The integration of these modern straw management techniques has made farming more efficient and environmentally sustainable, highlighting the significant progress from the labour-intensive past to the sustainable practices of today.

Keywords: Combine harvester: Integrated straw management system: Straw chopping and spreading: Sustainable residue management: Soil health improvement.

Introduction

Managing the leftover straw was a substantial challenge. In many regions, the straw was either left in large piles to rot or, more commonly, burned in the field to clear space for the next crop. This practice, while efficient for clearing fields, had several negative consequences. It led to air pollution, the loss of valuable organic matter that could enrich the soil, and an overall degradation of soil quality due to the lack of decomposed straw being returned to the ground (Spokas et al., 2016). The method of straw management not only affects soil fertility and organic matter levels but also impacts the overall sustainability of the cropping system (Lenaerts et al., 2012). In regions like South Asia, the problem is particularly acute due to intensive cropping systems and the short window between successive crops. This situation has led to common but harmful practices like stubble burning, which causes significant air pollution and leads to the loss of valuable soil nutrients. As awareness of these issues grows, attention has shifted toward more sustainable methods of residue management, with particular focus on mechanization and in-situ handling techniques (Lohani et al., 2018). The combine harvester combines reaping, threshing, and winnowing into a single, continuous operation, has become indispensable in large-scale cereal production. Early adoption, however, was limited to large farms due to high costs and limited accessibility. Over time, technological advancements and government interventions have facilitated the broader dissemination of combine harvesters, including smaller and regionally adapted models (singh et al., 2020). While these machines enhanced harvesting efficiency, conventional models lacked provisions for effective in-situ straw management.

As a result, harvested fields were often left with long stubble and concentrated straw deposits, impeding tillage and seedbed preparation for subsequent crops. Farmers, faced with narrow inter-seasonal windows, resorted to burning the residue to expedite land preparation, inadvertently triggering a cycle of environmental degradation and nutrient loss (Fusi et al., 2014). Moreover, straw management systems today also include baling capabilities, where the straw can be collected, compressed, and stored for later use. This could be for animal bedding, for use as forage, or even for selling as a biomass fuel source. Baling allows farmers to efficiently manage large volumes of straw while retaining its economic and environmental value. For instance, straw used as animal bedding can improve farm operations by reducing the need to buy synthetic bedding materials, while also providing a renewable resource that can be reused (Lenaerts et al., 2012). The modern combine harvester, with its sophisticated straw management systems, represents a leap forward in terms of both efficiency and environmental stewardship. By returning valuable organic matter to the soil, reducing the need for burning, and offering alternative uses for straw, these advanced machines are not only improving the economics of farming but are also playing a critical role in making agriculture more sustainable (Bhattacharyya et al., 2021).

The working mechanisms of combine harvesters with a focus on identifying the relationships between adjustment parameters and key performance indicators. Numerous researchers have investigated energy saving possibilities by increased stubble height and different straw management in cereal harvesting, economic performance of combine harvester, straw chopper/spreader development and socio-economic evaluation of the paddy residue management technologies (Jokiniemi_ et al., 2015 ; Hossain et al., 2015; Spokas et al., 2016; Zhang et al., 2017; Lohan et al., 2018; Belinsky et al., 2019; Praveen et al., 2020; Amiri, et al., 2022; Halko et al., 2023; Singh et al., 2024; Mamatov et al., 2025). By combining field trials, quantitative performance analysis, and theoretical modelling, this investigation aims to provide actionable insights for optimizing combine harvester operation under varied cropping systems. The outcomes will inform both machinery design improvements and user level best practices, contributing to the broader goals of sustainable intensification and mechanized precision agriculture. The present study proposes to assess the effect of integrated use of combined harvester with straw management. Further, agronomical impacts and performance of combined harvester with integrated straw management system were also reviewed.

Material and Methods

Study Area and Field Selection

The study was carried out in Allahabad, Uttar Pradesh, India—an important wheat-producing region. The climate during the wheat harvest season (April–May) is typically hot, with temperatures often exceeding 40 °C, which significantly affects both harvesting timing and practices. Two representative field sites within Uttar Pradesh were selected to reflect the prevailing soil conditions, climatic environment, and agronomic practices of the region. Wheat (Triticum aestivum), the major Rabi (winter) crop of the region, was chosen for the study. The crop was harvested during the Zaid season (April–May), when wheat reaches full maturity and attains a golden colour, indicating readiness for harvest. This period of high temperature accelerates grain ripening and influences harvester performance and field operations. One field site employed a combine harvester equipped with an integrated straw management system (treatment), which cuts, threshes, and separates grains while either chopping and uniformly spreading straw across the field or collecting it for subsequent handling (e.g., baling). The second field site followed traditional harvesting practices (control) without the use of an integrated straw management system.

Agronomical Parameters

A set of measurable indicators was used to evaluate crop growth, yield performance, and soil and field conditions under different agricultural practices. These indicators covered variations in irrigation practices, fertilizer application, tillage systems, pest management strategies, and harvesting methods, particularly focusing on the use of combine harvesters with integrated straw-management systems. Wheat yield (kg/ha) was recorded for both treatments—integrated straw management and traditional harvesting. The proportion of straw retained on the soil surface post-harvest was quantified to evaluate residue retention efficiency.

A straw decomposition assessment was carried out by marking straw piles in the field and determining the remaining biomass after 30 days, providing insight into breakdown rates and potential contributions to soil organic matter. Soil samples were collected before and after harvesting to analyse changes in soil organic matter, pH, moisture content, and compaction, enabling assessment of the effects of straw management on soil fertility and structure. In addition, weed pressure was monitored by measuring weed density (no. of weeds/m^2) in both treatments before and after harvest to determine the influence of straw retention on weed suppression.

Machine Performance Evaluation

The performance evaluation of the harvesting systems was conducted by measuring key operational and field parameters, including fuel consumption per hectare, time required per hectare, harvest losses, uniformity of straw distribution, and quantity of baled straw produced per hectare. Statistical analysis was performed using Analysis of Variance (ANOVA) to determine the significance of differences between treatments.

Operational performance was compared between the two practices—integrated straw-management combine harvesting and traditional harvesting—by assessing fuel efficiency, field capacity (harvesting speed), and machine downtime. In addition, a cost–benefit analysis was carried out by comparing the operational inputs (fuel usage, labour requirements, machine operating hours) with the agronomic benefits, such as improvements in soil health, weed suppression, and crop yield.

Results and Discussion

The comparison between integrated straw management and traditional harvesting practices clearly indicates the benefits of retaining and managing crop residue during wheat production. In both treatments, the seed rate was kept constant at 120 kg/ha, ensuring that differences in performance can be attributed to management practices rather than planting density. The integrated straw-management system resulted in a higher germination rate (95%) compared to the traditional method (90%), reflecting better soil moisture retention and improved seed-bed conditions due to surface residue.

Crop growth observations also showed advantages for the integrated straw-management system. Plants produced an average of five tillers per plant under straw management, compared to four tillers under the traditional system, representing a 25% improvement in tillering. Similarly, crop productivity components showed positive responses, with 50 grains per spike recorded in straw-managed fields versus 45 in traditionally harvested fields. The weight of 1000 grains also increased from 40 g in the traditional practice to 42 g in the integrated straw-management treatment, indicating improved grain filling and better physiological conditions during the grain-filling stage.

These combined improvements in growth parameters translated into a higher grain yield. The integrated straw-management system achieved 4700 kg/ha, whereas the traditional system yielded 4200 kg/ha, resulting in an approximate yield advantage of 500 kg/ha or about 12%. This positive yield response can be attributed to enhanced soil moisture conservation, moderated soil temperature, improved nutrient cycling, and reduced weed competition facilitated by straw retention and proper distribution. Overall, integrated straw-management practices not only improved crop establishment and yield components but also enhanced final grain productivity compared to traditional harvesting methods. The wheat yield data is shown in Table 1.

Table 1 Wheat yield data

S. No.	Parameter	Integrated straw management	Traditional harvesting
1	Seed rate (kg/ha)	120	120
2	Germination rate (%)	95	90
3	Tiller count per plant	5	4
4	Grains per spike	50	45
5	1000-grain weight (g)	42	40

S. No.	Parameter	Integrated straw management	Traditional harvesting
6	Yield (kg/ha)	4,700	4,200

The harvester equipped with an integrated straw management system consumed 16.7% less fuel than the traditional method. The study found that harvest losses were reduced by 33.3% with the integrated system. This is due to better calibration of threshing and separation units, ensuring efficient grain collection, uniform straw distribution, minimizing grain entrapment in straw and enhanced rotor and sieve adjustments, reducing grain spillage.

The significantly higher straw coverage in fields with the integrated system has several advantages such as preventing soil erosion by reducing wind and water runoff, enhancing soil moisture conservation, reducing irrigation needs. The integrated system allows for efficient collection and baling of straw, which can be used for livestock fodder, providing an additional income stream, biofuel production, promoting sustainable energy use and industrial applications, including paper and compost production.

The increase in soil organic matter (SOM) in the integrated system indicates enhanced nutrient recycling, reducing dependency on chemical fertilizers. The significantly lower weed density in the integrated system is attributed to straw mulching, which suppresses weed germination, improved soil moisture retention, reducing conditions favorable for weed growth and reduced soil disturbance, minimizing the exposure of weed seeds to sunlight. This reduction in weeds leads to lower herbicide requirements, decreasing input costs for farmers. The integrated system increased harvesting efficiency by 27%, due to simultaneous cutting, threshing, and straw processing, reducing the need for additional operations.

The Table 2 demonstrate clear advantages of the integrated straw-management system over traditional harvesting methods. Both treatments were performed on equal field areas (10 ha), maintaining uniform baseline conditions. Wheat yield was higher under integrated straw management (4,700 kg/ha) compared to traditional harvesting (4,200 kg/ha), reflecting improved soil moisture retention, nutrient cycling, and reduced weed interference, which are consistent with findings reported by Singh et al. (2020) highlighting yield benefits from residue retention in wheat systems.

Fuel consumption was lower (20 L/ha) in the integrated system than in traditional harvesting (24 L/ha), suggesting improved operational efficiency. Harvest losses were also reduced from 60 to 40 kg/ha, indicating better handling and grain recovery, aligned with earlier work on combine efficiency under residue-managing harvesters (Kumar and Kaur, 2021). Straw coverage was significantly greater (95% vs 25%), and additional straw was collected for baling (6 bales/ha), consistent with modern integrated residue-management systems designed to maximize field retention and commercial straw recovery (ICAR, 2022).

Soil organic matter showed a 3.5% increase in the straw-managed field, while no improvement occurred under traditional harvesting, supporting research noting that retained straw enhances soil carbon, microbial activity, and long-term fertility (Lal, 2016; FAO, 2021). Weed density was lower (4 vs 12 plants/m²), demonstrating the residue mulch effect, which reduces light availability for weed germination—a trend previously documented in wheat residue studies (Chauhan, 2018). The integrated system also achieved a higher harvesting speed (1.4 vs 1.1 ha/hr) and required less machine maintenance, indicating greater operational efficiency and smoother machine performance.

The results clearly demonstrate that the combine harvester with the integrated straw management system offers significant advantages. The results clearly demonstrate that the combine harvester equipped with an Integrated Straw Management System (SMS) delivers multifaceted agronomic, operational, and environmental benefits. Beyond the primary objective of efficient crop harvesting, the system substantially enhances field residue handling, which is increasingly recognized as a cornerstone of conservation agriculture and sustainable land management.

Operationally, the combine harvester with ISMS achieved uniform and controlled chopping of straw

Table 2 Performance Comparison of Harvest Systems

S. No.	Parameter	Integrated Straw Management	Traditional Harvesting	Notes
1	Field Area (ha)	10	10	Same field size for both treatments
2	Wheat Yield (kg/ha)	4,700	4,200	Higher yield with integrated straw management
3	Fuel Consumption (L/ha)	20	24	Lower fuel consumption with straw management
4	Harvest Loss (kg/ha)	40	60	Minimum loss in straw management
5	Straw Coverage (%)	95	25	Better straw distribution with integrated management
6	Straw Baled (bales/ha)	6	0	Straw collected for baling under integrated system
7	Soil Organic Matter (%)	3.5% increase	No change	Improved soil health with straw retention
8	Weed Density (plants/m²)	4	12	Lower weed density due to mulch effect
9	Harvesting Speed (ha/hr)	1.4	1.1	Faster harvesting with integrated straw management
10	Machine Maintenance (hrs)	1	3	Fewer adjustments and smoother operation

residues, followed by lateral and rearward distribution across the harvested swath. This uniformity ensures homogeneous residue cover over the soil surface, a key requirement for subsequent agronomic operations, particularly in zero-tillage or reduced-tillage farming systems. Unlike conventional harvesting methods, which often leave clumped residues or necessitate additional passes for residue management, the ISMS-enabled combine eliminates the need for post-harvest residue redistribution, thereby reducing time, fuel consumption, and machinery wear. From an agronomic perspective, the retained and finely chopped straw functions as an organic mulch, playing a critical role in improving soil organic carbon (SOC) content over time. Field measurements and soil sampling conducted post-harvest showed a notable improvement in surface soil structure, characterized by increased aggregate stability, enhanced microbial biomass, and improved cation exchange capacity (CEC). These improvements directly contribute to soil fertility and nutrient retention, fostering a more resilient soil ecosystem conducive to high crop productivity. The collected data from the field experiments undergoes statistical analysis, comparative assessments, and performance evaluations to derive meaningful conclusions. Key metrics such as wheat yield, harvest losses, fuel efficiency, and straw residue management are analysed using statistical techniques like Analysis of Variance (ANOVA) and regression analysis to quantify differences between the two harvesting systems.

Conclusions

The distinction between the two systems lies in both functional performance and agronomic outcomes. Conventional combine harvesters primarily focus on grain recovery, leaving large quantities of unmanaged straw unevenly spread over the field, which necessitates follow-up handling operations. In contrast, combine harvesters equipped with straw-management systems efficiently process crop residues during the harvesting operation itself. This results in improved field conditions, reduced labour and fuel requirements, and enhanced timeliness for subsequent field preparation.

Agronomically, integrated straw-management contributes meaningfully to soil quality by increasing organic matter content, improving soil structure, enhancing moisture retention, and reducing erosion risk. Uniform residue distribution also creates favorable micro-environmental conditions for crop establishment, supporting principles of conservation agriculture and sustainable intensification. The findings affirm that adopting integrated straw-management technology offers dual benefits: it mitigates environmental issues such as open-field residue burning while simultaneously improving productivity and long-term soil health. Moving forward, scaling up this approach will require continued convergence of mechanization, precision residue-handling technologies, and ecological stewardship. Such synergistic efforts will be instrumental in developing resilient, resource-efficient, and sustainable agricultural systems capable of supporting future global food security

Data Availability Statement

The datasets generated during the current study are available from the corresponding author on reasonable request.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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