



Residue Management Methods in Wheat Cultivation: A Feasibility Analysis

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Abstract: Paddy residues are vital natural resources, and their reuse can significantly improve the physical, chemical, and organic properties of soils, leading to increased crop production. Managing crop residues presents a significant challenge to combine-harvested paddy fields within the rice-wheat cultivation system, which is predominantly employed in the Indian subcontinent. This study aims to present the performance evaluation of three sowing methods for wheat in the field after combine harvested paddy crop. The study was conducted at the Instructional Farm of Farm Machinery and Power Engineering Department, Swami Vivekanand College of Agricultural Engineering Technology and Research Station, Raipur, Chhattisgarh, India with three sowing methods such as the combination of a rotary mulcher with a zero-till seed cum fertilizer-drill (M1), zero-till seed cum fertilizer-drill (M2), and turbo happy seeder (M3). The field efficiency of tractor-operated implements such as a rotary mulcher, zero-till seed cum fertilizer-drill, and turbo happy seeder was measured as 66.1, 69.96, and 70.51%, respectively. The M3 sowing method was the most effective in reducing straw length by 71.02% and incorporating straw into the soil by 51.66%. M1 had a moderate reduction in straw length (41.50%) and a low incorporation rate of 7.37%. In contrast, the M2 method showed the least impact, with no reduction in straw length or soil incorporation. The operating costs per hectare for M3 (Rs. 2099) were significantly lower than those for M2 (Rs. 2300) and M1 (Rs. 3541) because there was less fuel consumption for the operation. So, the turbo happy seeder or M3 method outperformed M1 and M2 in residue and biometric parameters, plus economic analysis. Therefore, M3 can be recommended to use on farmers' fields for rice residue management after combine harvesting to boost soil health and crop yield.

Key words: Crop residues, turbo happy seeder, field efficiency, fuel consumption, operating cost.

The Indian economy revolves around agriculture, with a significant portion of its land devoted to agriculture in diverse agro-ecological zones. India achieved impressive crop yields including 112.18 mt of wheat, 121.46 mt of rice, 22.3 mt of maize, and 359 mt of sugarcane (Ministry of Agriculture and Farmers Welfare, 2023). This intensive agricultural production translates into substantial production of crop residues, both within and outside the agricultural sector. It is estimated that around 500-550 mt of crop residues are generated in the country every year. This crop residue serves many purposes, such as animal feed, soil mulching, composting, biofuel production, roofing material, and fuel sources for domestic applications. As a result, this crop residue has significant value for farmers. However, a substantial portion of them is often burned in fields to prepare the land for the next crop, thus wasting valuable resources.

The rice-wheat cultivation system covers major areas in Raipur district of Chhattisgarh. Rainfall primarily occurs during the southwestern monsoon, with an average annual precipitation of 1190 mm over 80 years of data, mostly concentrated between June and September. The months during and after the monsoon have moderate temperatures and winter is a dry, cold season (Guha *et al.*, 2021). When it comes to wheat cultivation, farmers face several constraints, one of the main ones being the limited time between paddy harvesting and wheat sowing. The shorter interval between paddy harvest and wheat sowing results in crop residue obstructing seeding operations, making it impossible for farmers to implement any management techniques. As a result, they considered burning to be a less time-consuming and cost-intensive method (Choudhary *et al.*, 2021; Glithero *et al.*, 2013).

Burning of crop residues affects soil microbial activity, critical nutrients, and organic matter, reducing the effectiveness of applying organic matter in the following cropping season. In addition, it causes the depletion of important nutrients such as potassium, sulfur, phosphorus, and nitrogen from the topsoil, reducing the long-term fertility of the land and making it unsuitable for agriculture. Burning one ton of paddy straw reduces organic carbon and also reduces 5.5 kg of nitrogen, 2.3 kg of phosphorus, 2.5 kg of potassium, and 1.2

kg of sulfur. Crop residues typically contain 80% nitrogen (N₂), 25% phosphorus (P), 50% sulfur (S), and 20% potassium (K). Residue incorporation enriches the soil with organic carbon and nitrogen but burning destroys beneficial microorganisms, depleting nitrogen and carbon critical for crop root growth (Modi *et al.*, 2020; Mehta and Badegaonkar, 2023).

Timely sowing of wheat with zero tillage increases yield and reduces costs by reducing soil maintenance, fuel and tractor maintenance, water use, and the need for fertilizers and herbicides. However, challenges arise with stubble and chaff accumulation, low wheel traction due to loosened straw, and inconsistent planting depth in paddy fields harvested with combines under conditions of high residue content (Shukla *et al.*, 2002). The zero-till fertilizer seed-drill system efficiently sows wheat after paddy crop harvesting without tillage, utilizing lower horsepower tractors. Problems of ground skids that may alter the plant populations (Dharmender *et al.*, 2022) can be addressed by using a microcontroller-based seed metering mechanism (Gautam *et al.*, 2019; Gautam *et al.*, 2023). Rotary mulchers chop straw into bits, and spread them across the field, forming a mulch layer with a roller. Mulchers aren't suitable for wet straw. Happy seeder or reversible MB plough can then plant wheat or incorporate straw into the soil respectively (Chaudhary *et al.*, 2019). Thus, the happy seeder is equipment that meets the fundamental requirements of conservation agriculture by drilling seeds straight into fields while keeping residues out and causing no soil disturbance.

When direct tillage is done correctly, timely sowing can be achieved with the same or even higher crop yields while saving efficiency, water, energy, and money on production (Sidhu *et al.*, 2007). Happy seeder has less advantage for uneven fields and requires constant monitoring when used at deep sowing depths, prolonging the germination period. It is effective only for a few hours during the peak wheat planting season and may not work in the early morning or late evening when the straw is wet with dew (Sharma *et al.*, 2019).

Several technical barriers prevent farmers from using crop residue management equipment, including a lack of affordable

Table 1. Details of the experimental field

Parameters	Specifications
Field size	62×50 m ²
Distance between plots	0.5 m
No. of plots	9
Plot size	5×60 m ²
Row to row distance	0.30 m
Variety	MTU-1010
Soil type	Sandy loam
Date of sowing	14/11/18

technology, a lack of technical know-how in operating gear, and the need for a high-power tractor to operate crop residue management equipment (Sofoluwe *et al.*, 2011). Farmers have identified several additional barriers to the adoption of in-situ crop residue management techniques, including concerns about subsidies, a lack of funding, the need for additional management expertise, high operational costs, concerns about lower crop yields and/or economic returns, unfavorable attitudes or perceptions, and institutional limitations (Mehta and Badegaonkar, 2023).

Quantitative assessment of these developed technologies for crop residue management has been lacking in recent years. It has also been found that soil physical properties, such as texture and organic matter content, significantly affect soil buffering capacity. As a result, these traits can interact with soil pH, affecting productivity and performance within the cropping system (Li *et al.*, 2019). To address the issue of open burning of rice straw and the subsequent delay in wheat sowing, an innovative implement known as

the turbo happy seeder was developed (Sidhu *et al.*, 2015). This implement manages rice residues by cutting paddy straw, picking and drilling in open soil, and mulching with the residues. This makes it possible to sow wheat immediately after harvesting paddy, thereby eliminating the problem of burning residue. It speeds up planting by 7-10 days and prioritizes environmental protection, increasing soil productivity while minimizing disruptions to the ecosystem.

By considering all the above issues, the developed implements have their advantages and disadvantages in managing the crop residues in the field. As well as their economical and feasibility analysis varies in different operating conditions. These issues contribute towards the farmers difficulty in choosing the appropriate implements for their fields. Therefore, the present study aimed to provide a thorough understanding of different sowing methods after paddy harvesting and their performance in the field.

Materials and Methods

Experimental field

The study was conducted at the Instructional Farm of Farm Machinery and Power Engineering Department of Swami Vivekanand College of Agricultural Engineering Technology and Research Station, Raipur, Chhattisgarh, India, during the *Rabi* season in 2018-19. Three different implements were used to analyze the feasibility of residue management in the

Table 2. Technical specifications of the machinery used in this study

Parameters	Specifications		
	Turbo happy seeder	ZTSCFD	Rotary mulcher
Power source	Tractor (45-55 HP)	Tractor (35 HP)	Tractor (35 HP)
Machine weight	500-550 kg	250 kg	577 kg
Width of machine	2.0-2.5 m	1.8 m	1.67 m
Row to row spacing	225 mm	200 mm	-
Number of rows	9-12	9-11	-
Furrow openers type	Inverted 'T'	Inverted 'T'	-
Diameter of rotor	140 mm	-	220 mm
Rotor speed	1360 rpm	-	540 rpm
Type of blade	Reversible straight	-	Y type
Number of depth wheel	Two	One	-
Minimum GW diameter	550 mm	380 mm	-
Number of beads on periphery of GW	15 (with sharp edges)	10	-

field. Other parameters considered in the field experiment are given in Table 1.

Residue management implements

The tractor-operated rotary mulcher was selected which had a circular hole filled with blades named as flails for paddy straw. The rotary mulcher and rotary shaft diameters were 1600 mm and 200 mm, respectively. A total of 18 flail swords were attached on a circular shaft in a circular motion. The design of the blades was a “Y” version. Power from the PTO to the gearbox is provided by a universal shaft. The power of the rotary shaft is given by the belt and pulley arrangement attached from the shaft going through the gearbox. The gearbox has a 6:9 gear ratio and the driving pulley diameter is 225 mm. A press roller having a cylindrical shape was provided behind the machine. The diameter of the printing roll was 160 mm and the length of the printing roll was 1600 mm. Other implements details are well presented in Table 2. Three types of residue management implements were selected rotary mulcher, zero-till seed cum fertilizer-drill (ZTSCFD), and turbo happy seeder, respectively as shown in Figure 1.

Measurement of performance parameters

Actual field capacity: The actual average machine coverage rate is based on the total time taken for field operation. The machine was operating at a certain speed (most likely) in a continuous manner for fieldwork, and the coverage area during that time was recorded to determine the per-hour output.

$$AFC = \frac{A}{T} \quad \dots(1)$$

where, AFC is the actual field capacity (ha hr⁻¹), A is the actual covered area (ha) and T is the total time taken by the implement to cover the area (ha).

Theoretical field capacity: Theoretical field capacity is defined as the 100% area covered based on 100% full-rated width.

$$TFC = \frac{W \times S}{10} \quad \dots(2)$$

where, TFC is the theoretical field capacity (ha hr⁻¹), W is the implement working width (m), and S is the operational speed (m s⁻¹).

Field efficiency: Field efficiency (%) may be defined as the ratio of AFC and TFC expressed in percentage.

$$\text{Field efficiency} = \frac{AFC}{TFC} \quad \dots(3)$$

Fuel consumption : The amount of fuel used is measured by filling the top of the tank before and after the test. During the measurement, the engine fuel tank was in a horizontal position. The quantity of fuel added later was considered the fuel consumed.

$$\text{Fuel consumption (L/h)} = \frac{\text{Total fuel used}}{\text{Total working hour}} \quad \dots(4)$$

Measurement of residue parameters

Length of cut: The length measurement of straws before and after the operation was done with the help of a meter tape having 1 mm of least count. Randomly from five spots having an area of 1 m², straws were picked for each treatment and measured for the length of cut.

Weight of straw : The weight measurement of straws collected before and after the operation was done with an electric weighing balance having an accuracy of 0.1 gm.

Measurement of biometric parameters

Plant population : The number of plants grown was calculated at 20 days after sowing (DAS) from the length of one meter in five rows



Rotary mulcher

Zero-till seed cum fertilizer drill

Turbo Happy Seeder

Fig. 1. Residue management implements operations in the field.

Table 3. Performance parameters of residue management implements

Implements	AFC (ha hr ⁻¹)	TFC (ha hr ⁻¹)	Field efficiency (%)	Fuel consumption (L hr ⁻¹)
Rotary mulcher	0.341	0.516	66.10	2.92
ZTSCFD	0.340	0.486	69.96	2.96
Turbo happy seeder	0.251	0.356	70.51	2.91

randomly to the average. After this, the number of plants per square meter is determined from each other.

Plant height: The height of plant was recorded on randomly selected five plants in each plot and marked to record various views. The height of this marked plant from the ground to the top of the sample with the help of measuring meters. This observation was recorded at 20 DAS.

Depth of root: Root depth is measured in inches from the base of the stem to the root tip. The soil was dug to the right depth and cut deep soil from five different areas in each area. This observation was recorded at 20 DAS.

Economic analysis

The economical use of different machines was carried out by using the straight-line method, considering standard assumptions for the different parameters to find out the cost of operation of different farm implements. The straight-line approach is one of the easiest and most used ways to depreciate an asset evenly during its useful life.

It assumes a constant loss of value. The straight-line technique calculates annual depreciation for agricultural machinery like residue management implements for no-tillage wheat cultivation. In evaluating the cost of machinery, several factors are considered: initial cost, purchase price, estimated useful life, wear, maintenance cost, salvage value, the value of the machinery at the end of its life, depreciation calculated by straight-line (Equation 5), and total operating costs including labor, fuel, maintenance, and repairs are summed up annually.

$$D = \frac{P-S}{L \times H} \quad \dots(5)$$

where, D is the depreciation value (rupees), P is the purchase price (rupees), S is the salvage price (rupees), L is the life of the machine (years) and H is the annual working hours (hrs).

Statistical Analysis

One one-way ANOVA (Analysis of Variance) test was performed to evaluate the residual parameters, biometric parameters, and cost of operation for three sowing methods of implements viz. M1 (rotary mulcher and zero-till seed cum fertilizer-drill), M2 (zero-till seed cum fertilizer-drill), and M3 (turbo happy seeder) with five replication. It was also conducted to assess the performance parameters of implements for wheat sowing in the field after combine harvested paddy crop. Statistical inferences were made at a 0.05 level of probability.

Results and Discussion

Performance parameters of residue management implements

The results of the residue management implement in terms of TFC, AFC, field efficiency, and average fuel consumption are presented in Table 3. Field efficiency of rotary mulcher, zero-till seed cum fertilizer-drill (ZTSCFD), and turbo happy seeder were found to be 66.1, 69.96, and 70.51%, respectively. A similar type of performance was also presented by other authors (Sidhu *et al.*, 2015; Jat *et al.*, 2013; Kumar *et al.*, 2018; Dharmender *et al.*, 2022). One-way ANOVA test found no statistically significant difference between groups of implements (p-value > 0.05) for the performance parameters of selected implements as shown in Table 4. However, the field efficiency of the turbo happy seeder was found little more than the other two selected implements. Another, the average fuel consumption in the implement operation was comparable to each other (range of 2 to 3 L h⁻¹) but when seed sowing operation was considered, the M1 method consumed 5.88 L h⁻¹. It means that the M1 method of wheat sowing after combine harvested paddy crop consumed approximately double of fuel (L hr⁻¹) than other two methods of wheat sowing M2 and M3 in the field because M1 method involves two combined operations of rotary mulching and seed sowing. The M3 method

Table 4. ANOVA for residue management implements.

Source of Variation	SS	df	MS	F	P-value
Between Groups	2.705	2	1.353	0.0012	0.999
Within Groups	10309.63	9	1145.514		
Total	10312.33	11			

SS = sum of squares, df = degree of freedom, MS = mean sum of squares, F = F-statistic.

Table 5. Average length and weight of paddy straw per square meter

Methods	Straw length per square meter			Weight of straw per square meter		
	Before operation (cm)	After operation (cm)	Reduction in length (%)	Before operation (cm)	After operation (cm)	Incorporation of straw (%)
M1	15.92	9.30	41.50	149.21	138.20	7.37
M2	15.92	15.92	0.00	149.21	149.21	0.00
M3	85.62	24.80	71.02	444.90	215.06	51.66

had the extra advantage as compared to the M2 method in that the turbo happy seeder features a powered blade in front of the drill to cut crop residue, preventing the drill behind it from getting stuck. Overall based on performance parameters, the turbo happy seeder or M3 method was found better than the M1 and M2 methods in rice residue management when comparing the implements involved in these methods.

Effect of sowing methods on residue parameters

The length and weight of paddy straw m^{-2} were recorded before and after the operation for each treatment and obtained results are

shown in Table 5. Among the three sowing methods evaluated, M3 was the most effective in reducing straw length by 71.02% and incorporating straw into the soil by 51.66%. M1 had a moderate reduction in straw length (41.50%) and a low incorporation rate of 7.37%. In contrast, M2 showed the least impact, with no reduction in straw length or soil incorporation. Similarly, Ramulu *et al.* (2023) also presented a reduction of chopped paddy residue by rotary straw chopping machine and mixing with soil. These results suggested that the M3 showed promise for efficiently breaking down straw and incorporating it into soil, potentially providing benefits for improved agricultural practices and soil health (Table 5). The effect of

Table 6. ANOVA for sowing methods based on length and weight of paddy straw

Source of variation	SS	df	MS	F	P-value
Length of straw before operation					
Between Groups	16193.633	2	8096.817	2983.718	6.5332E-17
Within Groups	32.564	12	2.714		
Total	16226.197	14			
Length of straw after operation					
Between Groups	800.833	2	400.417	55.562	8.57101E-07
Within Groups	86.48	12	7.207		
Total	887.31	14			
Weight of straw before operation					
Between Groups	291437.98	2	145718.989	14696.357	4.6194E-21
Within Groups	118.984	12	9.915		
Total	291556.96	14			
Weight of straw after operation					
Between Groups	19695.631	2	9847.816	1512.356	3.80773E-15
Within Groups	78.139	12	6.512		
Total	19773.77	14			

SS = sum of squares, df = degree of freedom, MS = mean sum of squares, F = F-statistic.

Table 7. Effect of three sowing methods on biometric parameters

Methods	Plant population m ⁻¹ 20 DAS	Plant height (cm) 20 DAS	Depth of root (cm) 20 DAS	Cost of operation (Rs. ha ⁻¹)
M1	77	23.14	5.67	3541
M2	65	19.75	6.33	2300
M3	66	21.25	8.67	2099

Table 8. ANOVA for sowing methods based on biometric parameters

Source of variation	SS	df	MS	F	P-value
Plant population per meter of row length					
Between groups	443.33333	2	221.66667	1.6964286	0.224477
Within groups	1568	12	130.66667		
Total	2011.3333	14			
Height of plants (20 DAS)					
Between groups	28.857	2	14.4285	1.2474927	0.321944
Within groups	138.792	12	11.566		
Total	167.649	14			
Root depth of plants (20 DAS)					
Between groups	24.82576	2	12.41288	2.1559309	0.158514
Within Groups	69.0906	12	5.75755		
Total	93.91636	14			

SS = Sum of squares, df = Degree of freedom, MS = Mean sum of squares, F = F-statistic.

three sowing methods after combine harvested rice residue on residue performance parameters was found to be highly significant as ANOVA results presented in Table 6.

The analysis revealed a significant difference in the length of straw before and after operation across the treatments (p -value < 0.05). The M3 exhibited a substantial reduction in straw length after the operation compared to M1 (rotary mulcher plus zero till seed cum fertilizer drill) and M2 (zero till seed cum fertilizer drill). This reduction in straw length could be attributed to the efficiency of the turbo-happy seeder in managing crop residues (Jat *et al.*, 2013). Similar to the length of the straw, the weight of the straw before and after the operation showed significant differences among the treatments (p -value < 0.05). The M3 demonstrated a considerable reduction in straw weight after the operation because of the straw incorporation in the soil, indicating effective residue management compared to M1 and M2.

Effect of sowing methods on biometric parameters

Data obtained for the three sowing methods on biometric parameters are presented in Table 7. The average plant population m⁻¹ of row length in M1 and M2 sowing methods were

found to be 77 and 65 respectively. Similarly, for the M3 sowing method, the average plant population was found as 66 in one meter. However, the plant heights in M1, M2, and M3 were found to be 23.14, 19.75, and 21.25 cm, respectively at 20 DAS. It was found more in the M1 sowing method and the M2 method. A similar type of study was also conducted by Singh *et al.* (2014) presenting the effect of different combining operations of tillage and seeding with ZTSCFD (zero-till ferti-seed drill) on economical and wheat crop growth parameters and yield. In terms of the average depth of root, the M3 sowing method (8.67 cm) showed more value than M1 (5.67 cm) and M2 (6.33 cm). The M3 method found to be a comparative in terms of biometric parameters, suggesting better crop production. This may be due to the efficient operation of the turbo-happy seeder (Iqbal *et al.*, 2017). When the one-way ANOVA test was performed on the obtained biometric parameters, it was found that there were no significant differences among sowing methods (p -value > 0.05) as shown in Table 8. However, M3 consistently outperformed M1 and M2 in promoting plant growth.

Similarly, the authors (Singh *et al.*, 2013) also mentioned that the turbo-happy seeder had a positive impact on early plant development

which resulted in better crop production in rice residue fields.

Economic analysis

The total cost of operation for the M1, M2, and M3 sowing methods were obtained as 3541, 2300, and 2099 Rs. ha⁻¹, respectively (Table 7). The lowest operational cost was found in the M3 method because there was less fuel consumption for the operation.

Thus, researchers can also examine the long-term effects of various residue management strategies on agricultural productivity, soil health, and sustainability in general. Studies with a longitudinal design may shed light on the resilience and sustainability of cropping systems over several growing seasons evaluating the impacts of different residue management techniques on soil carbon sequestration, greenhouse gas emissions, and biodiversity, among other environmental ramifications. Life cycle analyses could be used to compare the overall environmental impact of various techniques. The investigating methods to promote the broad implementation of residue management techniques, especially in areas where tillage-based agriculture is the predominant agricultural practice and among smallholder farmers. This could entail partnerships with regional stakeholders, policy support, outreach activities, and capacity-building initiatives.

Conclusions

Among three different residue management implements, the field efficiency of the turbo happy seeder (70.51%) was found more than the other two selected implements' operation (Rotary mulcher and zero-till seed cum fertilizer drill) for wheat sowing after combine harvested paddy crop. Among the three sowing methods (M1, M2, and M3) evaluated, M3 was the most effective in reducing straw length by 71.02% and incorporating straw into the soil by 51.66%. M1 had a moderate reduction in straw length (41.50%) and a low incorporation rate of 7.37%. In contrast, M2 showed the least impact, with no reduction in straw length or soil incorporation. The lowest operational cost was found in the M3 sowing method (2099 Rs. ha⁻¹) because there was less fuel consumption for the operation. Based on the obtained results, it was concluded that the turbo happy seeder or M3 method is best

for wheat sowing in combine harvested paddy fields. So, the turbo happy seeder or M3 method resulted in superior performance compared to the other M1 and M2 sowing methods in terms of residue parameters, biometric parameters, and economic analysis. Therefore, it can be recommended to use on farmers' fields for rice residue management after combine harvester fields for better soil health and crop production.

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