Comparison of Straw Chopper cum Incorporator with Existing Paddy Residue Management Technologies in Combine Harvested Paddy Field at North Western Region of India

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Authors' contributions

This work was carried out in collaboration among all authors. Author CR designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author RNP managed the analyses of the study and guided during entire research work. Author MAN managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Burning of paddy residue is major problem which leads to adverse affect on our environment. Management of crop residues in conservation agriculture is vital for long-term sustainability of Indian agriculture. The straw chopper cum incorporator machine consists of chopping unit, incorporation unit, adjustable frame, pulleys and belts. The power is transmitted to the chopping unit and incorporation unit by tractor (55.95 kW) PTO with the help of gear box, belt, pulley and gear arrangement. The fuel consumption, field capacity and field efficiency of residue management machine were observed 12.5-14.0 l/h, 0.43-0.64 ha/h and 60.46% respectively. Cost economics of straw chopper cum incorporator machine was compared with existing technologies adopted by farmers i.e. straw chopper + 2 rotavator practice and 6 harrowing + rotavator + planker practice. The cost of operation of straw chopper cum incorporator machine was observed 4272.8 Rs.ha⁻¹ lower than existing technologies. The break even point (BEP), pay back period and benefit cost (B:C) ratio of the Straw chopper cum incorporator machine were 45ha, 0.7 years and 1.17

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respectively. Therefore, it is concluded that the Straw chopper cum incorporator machine can be recommended to the farmers for paddy residue management of combine harvested paddy field.

Keywords: Straw chopper cum incorporator; burning; paddy residue; chopping; incorporation; cutting and conservation agriculture.

1. INTRODUCTION

The agricultural industry plays a major role in the overall economic growth of the world. Specifically, India is the second largest producer of rice and wheat in the world, two crops that usually produce large volume of residue. On an average, for every 4 t of wheat or rice, about 6 t of straw is produced which shows a huge amount of straw available for disposal every year. The total yield of paddy straw in combine harvested field is about 12.5 t/ha in which yield of standing stubbles and loose straw is about 7 t/ha and 5.5 t/ha, respectively [7]. Overall, India produces 686 MT gross crop residue biomass on annual basis, of which 234 MT (34% of gross) are estimated as surplus biomass. At state level, Uttar Pradesh produces the highest amount of crop residue amongst all the 29 states. Amongst all the crops, sugarcane produces the highest amount of surplus residue followed by rice. A total of 39 residues from 26 crops cultivated in India are considered for the study [4].

The sowing of wheat is recommended by the 30th November for obtaining higher yield. Thus, the total time available for timely sowing of wheat is about 15-20 days after combine harvesting paddy field. Farmers are unable to prepare the seedbed within this limited time, due to this reason farmers burns the paddy straw [3]. Burning of crop residues leads to release of soot particles and smoke causing environmental problems, emission of greenhouse gases (GHGs) such as carbon dioxide, methane and nitrous oxide causing global warming, loss of plant nutrients such as N, P, K adverse impacts on soil properties and wastage of valuable organic carbon and energy rich residues. Open burning of paddy straw in fields releases pollutants into the atmosphere that contribute to enhance climate change issues [7]. Despite the known of its benefits, growers burn a significant portion of the crop residues on-farm so that the succeeding crop can be sown. Mechanized farming linked with lack of low-skilled farm labour and high initial cost of residue management machine further exacerbates the problem of on-farm burning of crop residues [9].

Possible alternatives to burning of crop residues with a chemical adjuvant, reducing the residue particle size by shredding and then incorporating the residue into the soil. Shredding of the trash would reduce the particle size, increasing surface area from which microbes could degrade the residue quickly. Results of shredding crop residue have generally hastened the degradation rate as indicated by increased carbon and nitrogen mineralization, altered the peak respiration time, or did not affect respiration. Soil incorporation with residues would also increase the residue surface that would come in contact with soil microbes and thus hasten decomposition [1].

Management of crop residues in conservation agriculture is vital for long-term sustainability of Indian agriculture. Burning of residues must be stopped and should be used positively for conservation agriculture (CA) for improving soil health and reducing environment pollution. Even in regions where crop residues are used for animal feed and other useful purposes, some amount of residues must be recycled to soil. Conservation agriculture benefits farmer because it reduces production costs and increases yield. Development of appropriate farm machinery is to facilitate the application of residues, and successful planting of a crop in the rotation under a layer of residues on soil surface [2]. Incorporation of paddy (Oryza sativa L.) straw, compared with burning, affects soil nitrogen supply by increasing nitrogen and carbon inputs. Data indicated the decrement in fertilizer nitrogen utilization efficiency (FNUE) with a concomitant and more significant increase in the plant available nitrogen [11]. Incorporation of high and medium amounts of wheat straw had significant effects on increasing the soil N, P and K and the incorporation of crop residues significantly increased the grain production per unit area. Straw incorporation was the most effective practice for improving the soil properties and fertility, which can be recommended for crop residue management system to enhance both agricultural productivity and sustainability [12].
There is urgent need of new technologies which gives proper utility to soil by the paddy residue and popularizing this type of innovations because paddy straw has immense economic potential for the farmers popularizing the new innovations and new alternative techniques for paddy straw management [8]. The machinery available for crop residue management in are happy seeder, rotavator, zero seed drill, straw baler, paddy straw chopper and super straw management system on combine. The straw chopper cum incorporator can cut the stubbles and mix with other vegetable growth if any on the field. By keeping above views in mind the paddy residue management machine for combine harvested paddy field was developed and the cost economics was compared with existing paddy residue management technologies.

2. MATERIALS AND METHODS

2.1 Description about Straw Chopper cum Incorporator

Basically the straw chopper cum incorporator is the combination of straw chopper and rotavator with the adjustable frame. The developed frame has the superiority that is the horizontal and vertical clearance between straw chopper rotor shaft and rotavator shaft can be adjusted on either side. The purpose of this adjustment was made because the horizontal and vertical clearances that may affect the performance of our developed machine [5]. The straw chopper has inverted gamma type blades and rotavator with L- type blades will incorporate processed paddy residues. The straw chopper cum incorporator performs the job of straw chopping and incorporation in a single pass. Therefore, due to incorporation of paddy residue in soil would increases the decomposition rate of paddy residue and thus improves the soil health. Isometric view from rear side of straw chopper cum incorporator is shown in Figs. 1 and 2. Detail specification of the Straw chopper cum incorporator is presented in the Table 1.

2.2 Paddy Residue Management Practices

The main emphasis of economics comparison of that Straw chopper cum incorporator machine with existing technologies used by farmers is that to know whether this Straw chopper cum incorporator machine is economically viable or not. So the cost economics of this Straw chopper cum incorporator machine were compared with two available existing technologies for residue management. Those technologies were combination of straw chopper and rotavator. The second one is conventional residue management operations used by farmers prior to sowing of wheat i.e 6 harrowing + 2 planking. The specifications of the machinery used for cost economic comparison were shown in Tables 2, 3 and 4. These machineries were operated by using tractor of 33 kW. The cost economics comparison of straw chopper cum incorporator and existing technology were carried out by calculating the cost of operation of straw chopper cum incorporator with existing practices. The Fig. 3 illustrates residue management practices during field evaluation. The cost of operation was determined by standard procedure.

![Fig. 1. Side view of the straw chopper cum incorporator](image)

(All dimensions are in millimetre only)
Table 1. Specification of the straw chopper cum incorporator

| S. no. | Particulars                                                      | Dimensions                        |
|-------|------------------------------------------------------------------|-----------------------------------|
| 1     | Length X Width X Height                                          | 1900 X 2100 X 950 mm              |
| 2     | Weight of the machine (W)                                        | 900 kg                            |
| 3     | Power requirement                                                | 56 kW                             |
| 4     | Number of working elements in chopper                            | 22                                |
| 5     | Type of flails in chopper                                        | Inverted gamma type               |
| 6     | Speed of Flail shaft in chopper                                  | 900-1500 rpm                      |
| 7     | Shape of working elements in rotavator                           | L shape                           |
| 8     | Speed of rotavator shaft                                         | 180-210 rpm                       |
| 9     | Number of working elements in rotavator                          | 48                                |
| 10    | Mode of Power Transmission                                       | Belt, pulley and spur gears       |

Fig. 2. Isometric view of the straw chopper cum incorporator from rear side

Fig. 3. Field evaluation of existing paddy residue management technologies considered under this study

Table 2. Specifications of the straw chopper

| S. no | Particulars                        | Specifications                  |
|-------|------------------------------------|---------------------------------|
| 1     | Type of machine                    | PTO driven, mounted type        |
| 2     | Power source, kW                   | Tractor of 34                   |
| 3     | Overall dimensions                 |                                 |
| 4     | Length X Width X Height, mm        | 900 X 1900 X 930                |
| 5     | Number of flails                   | 22                              |
| 6     | Flail spacing, cm                  | 20                              |
| 7     | Shape of flail                     | Inverted gamma type             |
| 8     | Transmission                       |                                 |
| 9     | Diameter of drive pulley, mm       | 198                             |
| 10    | Type of pulley                     | B category, V-belt              |
| 11    | Number of pulley                   | 2                               |
| 12    | Type of make                       | MASCHIO                         |
| 13    | Price of machine, Rs.              | 161000                          |
Table 3. Specifications of the rotavator

| S. no. | Particulars            | Specifications                 |
|-------|------------------------|--------------------------------|
| 1     | Type of machine        | PTO driven, mounted type       |
| 2     | Power source, kW       | Tractor of 34                  |
| 3     | Overall dimensions     |                                |
| 4     | Length X Width X Height, mm | 2360 X 900 X 930              |
| 5     | Number of flanges      | 8                              |
| 6     | Blades per one flange  | 6                              |
| 7     | Number of working components | 48                          |
| 8     | Shape of blades        | L-type                         |
| 9     | Transmission           |                                |
| 10    | Type of power transmission | Gear drive                |
| 11    | Number of gears        | 3                              |
| 12    | Type of make           | DASMESH Rototiller             |
| 13    | Price of machine, Rs.  | 80000                          |

Table 4. Specifications of disc harrow

| S.No. | Particulars            | Specifications                 |
|-------|------------------------|--------------------------------|
| 1     | Type of machine        | Offset disc harrow, Tralled    |
| 2     | Power source, Kw       | Tractor of 34                  |
| 3     | Overall dimensions     |                                |
| 4     | Length X Width X Height, mm | 1700 X 1900 X 700             |
| 5     | Number of gangs        | 2                              |
| 6     | Number of discs per gang | 8                        |
| 7     | Number of working components | 16                      |
| 8     | Diameter of disc, mm   | 600                            |
| 9     | Type of make           | Jai Gurudev Industries, Rudrapur |
| 10    | Price of machine, Rs.  | 50000                          |

2.3 Estimation of Cost of Operation

The cost of operation of Straw chopper cum incorporator machine was determined by straight line method by considering fixed and variable cost [6]. The sum of fixed and variable cost is operational cost.

\[
\text{Cost of operation} = \frac{F.C + V.C}{H} \quad (1)
\]

Where,
- \(F.C = \text{Total fixed cost}\)
- \(V.C = \text{Total variable cost}\)
- \(H = \text{Working hours}\)

2.3.1 Fixed cost

2.3.1.1 Depreciation

Depreciation is the reduction in the value of a machine with time and use. It is the ratio of the total cost of the machine minus salvage cost by assuming life of 10 years multiply with the 250 annual working hours of designed prototype [6]. It is calculated under fixed cost.

\[
D = \frac{C - S}{L \times H} \quad (2)
\]

where,
- \(D = \text{Depreciation, Rs.h}^{-1}\)
- \(C = \text{Initial cost of machine, Rs.}\)
- \(S = \text{Salvage value (10% of C in Rs.)}\)
- \(L = \text{Expected life of machine (10 years)}\)
- \(H = \text{Annual working hours (Assumed 200 h)}\)

2.3.2 Interest cost

Interest cost is included in the fixed cost. It was calculated from capital investment taking 12% as interest. The interest cost is determined by following relationship:

\[
\text{Interest cost (I)} = \frac{C + S \times i}{2 \times H} \quad (3)
\]

where,
- \(I = \text{Interest cost, Rs. h}^{-1}\)
- \(I = \text{Rate of interest,}\%\)

2.3.3 Variable cost

2.3.3.1 Repair and maintenance

Repair and maintenance cost are difficult to determine as they greatly depending upon...
Table 5. Cost of operation of a straw chopper cum incorporator machine

| S. no. | Parameter                              | Tractor super 75 | Straw chopper cum incorporator machine |
|--------|---------------------------------------|------------------|----------------------------------------|
|        | Fixed cost (Rs/h)                      |                  |                                        |
| 1      | Initial cost (Rs.)                     | 950000           | 250000                                 |
| 2      | Solvage value (Rs.)                    | 95000            | 25000                                  |
| 3      | Expected life (yr)                     | 10               | 10                                     |
| 4      | Annual working hours (h)               | 1000             | 200                                    |
| 5      | Depreciation (Rs.)                     | 85.5             | 112.5                                  |
| 6      | Interest (Rs.)                         | 62.7             | 16.5                                   |
| 7      | Repair and maintenance (Rs.)           | 9.5              | 1.25                                   |
| 8      | Housing and insurance (Rs.)            | 0.95             | 0.25                                   |
| 9      | Total                                  | 158.65           | 130.50                                 |
|        | Variable cost (Rs./h)                  |                  |                                        |
| 10     | Fuel cost@68Rs.                        |                  | 850                                    |
| 11     | Lubricant cost @20% of fuel cost       |                  | 170                                    |
| 12     | Labour cost @50Rs./h                   |                  | 400                                    |
| 13     | Total                                  |                  | 1420                                   |
| 14     | Total cost of operation (Fixed+Variable) (Rs./h) | 158.65 | 1550.5                                 |
| 15     | Effective field capacity (ha/h)        |                  | 0.4                                    |
| 16     | Total cost of operation (Tractor+ Straw chopper cum incorporator machine) (Rs./ha) | 4272.88          |                                        |

Table 6. Cost of operation of a straw tractor + chopper + rotavator

| S. no. | Parameter                              | Tractor 5310 | Straw chopper | Rotavator |
|--------|---------------------------------------|--------------|---------------|-----------|
|        | Fixed cost (Rs./h)                     | 800000       | 161000        | 80000     |
| 1      | Initial cost (Rs.)                     | 80000        | 16100         | 8000      |
| 2      | Solvage value (Rs.)                    | 10000        | 200           | 200       |
| 3      | Expected life (yr)                     | 10           | 10            | 10        |
| 4      | Annual working hours (h)               | 1000         | 200           | 200       |
| 5      | Depreciation (Rs.)                     | 72           | 72.45         | 36        |
| 6      | Interest (Rs.)                         | 10.63        | 10.63         | 5.28      |
| 7      | Repair and maintenance (Rs.)           | 8            | 0.805         | 0.4       |
| 8      | Housing and insurance (Rs.)            | 0.8          | 0.16          | 0.08      |
| 9      | Total                                  | 133.6        | 84.04         | 41.76     |
### Table 7. Cost of operation of a tractor + 6XHarrowing + rotavator + planker

| S. no. | Parameter | Tractor 5310 | 6 Harrowing | Rotavator | Planker |
|--------|-----------|--------------|-------------|-----------|---------|
|        | Fixed cost (Rs./h) |              |             |           |         |
| 1      | Initial cost (Rs.) | 800000       | 50000       | 80000     | 25000   |
| 2      | Salvage value (Rs.) | 80000        | 5000        | 8000      | 2500    |
| 3      | Expected life (yr) | 10           | 10          | 10        | 1       |
| 4      | Annual working hours (h) | 1000        | 200         | 200       | 200     |
| 5      | Depreciation (Rs.) | 72           | 22.5        | 36        | 11.25   |
| 6      | Interest (Rs.) | 52.8         | 3.3         | 5.28      | 1.65    |
| 7      | Repair and maintenance (Rs.) | 8           | 0.25        | 0.4       | 0.125   |
| 8      | Housing and insurance (Rs.) | 0.8         | 0.05        | 0.08      | 0.03    |
| 9      | Total | 133.6        | 26.10       | 41.76     | 13.05   |
|        | Variable cost (Rs./h) |              |             |           |         |
| 10     | Fuel cost@68Rs. |              | 60.18       | 452.88    | 238     |
| 11     | Lubricant cost @20% of fuel cost |              | 12.04       | 90.58     | 47.60   |
| 12     | Labour cost @50Rs./h |              | 400         | 400       | 400     |
| 13     | Total | 0            | 472.216     | 943.456   | 685.6   |
| 14     | Total cost of operation (Fixed+Variable) (Rs./h) | 133.6       | 498.32      | 985.22    | 698.65  |
| 15     | Effective field capacity (ha./h) |              | 0.81        | 0.71      | 0.828   |
| 16     | Total cost of operation (Rs./ha) |              | 6X780.143=4680.86 | 1575.80   | 1005.13 |
| 17     | Total(harrow+rotavator+Planker) (Rs./ha) |              | 7261.79     |          |         |
Table 8. Break even point, pay back period and B:C ratio

| S. no. | Variables                                    | Price  |
|-------|----------------------------------------------|--------|
| 1     | Total Fixed Cost (Rs./h)                     | 130.5  |
| 2     | Actual field capacity (ha/h)                 | 0.4    |
| 3     | Fixed cost (Rs. ha\(^{-1}\))                 | 326.25 |
| 4     | Variable Cost (Rs. ha\(^{-1}\))              | 3550   |
| 5     | Assumed shredding Fees (Rs. ha\(^{-1}\))     | 5000   |
| 6     | Working Hours (h)                            | 200    |
| 7     | Break-even Point (ha)                        | 45     |
| 8     | Amount of investment (Rs.)                   | 250000 |
| 9     | Expected annual net revenue (Rs.)            | 355000 |
| 10    | Pay Back Period (yrs)                        | 0.7    |
| 11    | Gross returns (Rs. ha\(^{-1}\))             | 5000   |
| 12    | Cost of operation (Rs. ha\(^{-1}\))         | 4272.88|
| 13    | B:C ratio                                    | 1.17   |

operating conditions, location of service store, maintenance programs, local cost, etc. repair cost per hour of use will increases with age but tend to level off as the machine become older. Repair and maintenance cost was considered 10% for tractor and 5% for Straw chopper cum incorporator machine.

2.3.3.2 Labour cost

Labour cost is an important consideration in comparing ownership to custom hiring. The major cost involved in chopping cum incorporating was calculated from man-hrs. By considering daily wages that was about 400Rs day\(^{-1}\) and taking into account that two labours were required to operate the machine.

2.3.3.3 Fuel cost

Fuel costs can be estimated by considering data of average fuel consumption during operation in l/h. Fuel cost was calculated by considering diesel rates at the rate of 68Rs. per litre.

2.3.3.4 Lubricating cost

As literature suggest that total lubrication costs on field operation average about 15-35% of fuel costs. Therefore, it was considered as 30% of fuel cost.

2.3.3.5 Housing and insurance cost

Housing and insurance were calculated by considering 1% each of initial cost of tractor/machine.

2.4 Break-Even Point (B.E.P)

The break-even point is equal to the annual fixed cost divided by difference between the custom rate per hour and the operating cost per hour. The break-even point was calculated by using following equation.

\[ \text{BEP} = \frac{FC}{CF - C} \]  \hspace{2cm} (4)

where,

- \(\text{BEP}\) = Break even point, ha
- \(FC\) = Annual fixed cost, Rs.year\(^{-1}\)
- \(CF\) = Custom hiring fee, Rs. ha\(^{-1}\)
- \(C\) = Operating cost, Rs. ha\(^{-1}\)

2.5 Payback Period

It is the number of year it would take for an investment to return its original cost through the annual cash revenues it generates, if the net cash revenues are constant each year. The payback period is calculated following equation.

\[ \text{P} = \frac{I}{E} \]  \hspace{2cm} (5)

where,

- \(\text{P}\) = Pay back period, years
- \(I\) = Amount of investment, Rs.
- \(E\) = Expected annual net revenue, Rs.

2.6 Benefit Cost Ratio

It is the ratio of annual benefit to annual cost. The B.C ratio must be unity or more for a project
investment to be considered worthwhile. This technique also ranks the project investments for selection. The ratio of unity indicates the coverage of costs without any surplus benefits. But usually the ratio has to be more than unity in order to provide some additional return over the costs for clear decision.

$$\text{B:C Ratio} = \frac{\text{Gross returns per ha}}{\text{Cost of operation per ha}}$$

(6)

3. RESULTS AND DISCUSSION

The comparison of Straw chopper cum incorporator machine was carried out with conventional residue management machinery i.e. 6 X harrowing + 1X rotavator +1 X planking and 1 X straw chopper + 2 X rotavator. The cost economics parameters of straw chopper cum incorporator includes cost of operation, break even point, pay back period and benefit cost ratio. The results obtained are presented in Table 8. The cost of operation of Straw chopper cum incorporator machine was calculated Rs. 4272.88 ha\(^{-1}\) and payback period was obtained 0.7 years if the machine would operate for 100 working hours per annum. Benefit cost ratio will be 1.17 with break even point of 45 ha. Cost effective with comparison to existing residue management machinery systems. The cost of operation of conventional operation was found Rs. 7261.79 ha\(^{-1}\). The cost of straw mulcher and rotavator recorded Rs. 5434.49 ha\(^{-1}\). The reason for cost of operation of Straw chopper cum incorporator machine was comparatively lower than existing technologies because Straw chopper cum incorporator machine require only single pass to complete the operation and operating cost of Straw chopper cum incorporator machine was comparatively lower than the operating cost of considered existing residue management technologies.

4. CONCLUSIONS

It was concluded that the Straw chopper cum incorporator machine was cost effective and can be recommended for the commercial use of the farmer for the effective paddy residue management and thus the soil health and environmental condition can be improvised. The Straw chopper cum incorporator machine reduces the size of paddy residue uniformly and mixes with the soil for biological activity of the soil by incorporation in single pass.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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