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Paddy straw management practices in Northern India for improved efficiency and techno-economic feasibility

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ABSTRACT

The study deals with the optimization of paddy residue management technologies for the management of paddy straw in combine harvested fields. The study emphasizes paddy straw management under different techniques (Retention, Incorporation and Removal of straw) with the use of different combinations of machinery. The research was conducted at farmer's field Dabra, Hisar, Haryana during 2017–18. The objective of the research was to evaluate techno-economic feasibility of different options of machinery. According to the results of the trials, the M_4 (Combine harvester with SMS + Reversible mould board plough + Rotavator + Seed drill) had the greatest fuel consumption of 53.12 l/ha. M_2 (Combine harvester with SMS + Spatial till drill) had the lowest fuel consumption of 22.29 l/ha. The lowest cost of operation of 63.32 ₹/q was found in treatment M_2. Highest unit cost operation of 140.52 ₹/q was found in M_9 (Traditional combine + Stubble shaver + Hay rake + Straw baler + Disc harrow (2 pass) + Planker + Seed drill). The benefit-cost ratio was found to be highest in traditional combine (1.99) and lowest in zero-till drill (1.11). Treatment-wise, benefit-ratio ratio was found maximum in treatment M_{10} (1.80) and minimum in M_5 (1.50). According to the findings of study, residue retention technology is found better in comparison to straw incorporation and straw removal.

Keywords: Cost of operation, Economics, Straw management, Wheat

The agriculture sector of India has occupied 43% of India's geographical area and is contributing 17% of India's GVA (Jaideep *et al.* 2018). However, due to lack of awareness, approx. 140 million tonnes (Mt) agricultural residue is set on fire after the harvesting of the crop for preparation of field for the following crop. This problem is much severe in regions where farmers are practicing the mechanized rice-wheat cropping pattern (Mehta *et al.* 2013). Rice and wheat crops were covering an area of 30.46 and 34.95 lakh ha in Punjab with total production of 188.63 and 176.36 lakh tonnes during 2016–17, respectively (Anonymous 2018 a and b, Parveen *et al.* 2020). Out of 82 Mt surplus residues from the cereal crops, 44 Mt is generated from rice and to follow 24.5 Mt is generated from wheat, which is mostly burnt on-farm (MNRE 2009). A total of 81% paddy straw is burnt in the field by the farmers in Punjab every year (Kumar *et al.* 2014, Parveen *et al.* 2020). In the year 2017 and 2018, total amount of agricultural residue burned in India was estimated to be 516 Mt and 116 Mt, respectively (Venkatramanan *et al.* 2021). Farmers in Punjab and Haryana, in particular, burn an estimated 35 MT of crop residue each year from their paddy fields after harvesting (Porichha *et al.* 2021).

There are lots of machines available for mulching purpose (Anonymous 2016). The use of no-till drills has its positive impacts on wheat yield (Kumar *et al.* 2013, Bansal and Kumar 2014). The use of rice straw mulch increases wheat grain yield, reduces crop water consumption by 3–11%, and improves water use efficiency by 25% (Chakraborty *et al.* 2008). Straw retention technology also resulted in lesser energy consumption and the yield obtained was also higher whereas energy consumption in straw incorporation and straw removal technologies was much higher (Parveen *et al.* 2021). In view of the above said facts, the present study on techno-economic feasibility of paddy straw management technologies was undertaken.

MATERIALS AND METHODS

In the present study (2017–18) out of ten treatments, the first three treatments were conducted on retention of paddy residue, and the next four based on incorporation of paddy straw whereas last three treatments were based on removal of paddy straw from the field.

Retention of paddy straw on field

M_1=Combine harvester with Straw management system (SMS) + Zero till drill; M_2= Combine harvester with SMS

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+ Spatial till drill; M_3=Combine harvester with SMS + Happy seeder.

Incorporation of paddy straw in soil

M_4 = Combine harvester with SMS + Reversible mould board plough + Rotavator + Seed drill; M_5 = Combine harvester with SMS + Rotavator (2 pass) + Seed drill; M_6 = Combine harvester with SMS + Disc harrow (3 pass) + Planker + Seed drill; M_7=Combine harvester with SMS + Rotavator + Manual broadcasting + Rotavator.

Removal of paddy straw from field

M_8 = Traditional combine + Stubble shaver + Straw baler + Disc harrow (2 pass) + Planker + Seed drill; M_9=Traditional combine + Stubble shaver + Hay Rake + Straw baler + Disc harrow (2 pass) + Planker + Seed drill; M_{10}=Traditional combine + Traditional straw removing method + Disc harrow (2 pass) + Planker + Seed drill.

Soil parameter

Types of soil: The soils of the Hisar district are broadly classified into three types. So, samples were taken from the upper layer of soil from the experimental field.

Soil moisture percentage: The soil moisture analysis was done by oven drying method. Moisture content was measured as;

$$\text{Moisture content of soil} = \frac{W_w - W_d}{W_d} \times 100$$

Where W_w = Weight of wet soil (g); W_d = Weight of the dry soil (g).

Bulk density: The bulk density was determined after the operation using core cutter and hammer as;

$$\rho = \frac{4M}{\pi D^2 L}$$

Where ρ=Bulk density, g/cc; M=Oven dry mass contained in soil sampler, g; V=Volume of cylinder sampler, cm^3; D=Diameter of cylinder sampler, cm; L=Height of cylinder sampler, cm.

Soil strength: Cone penetrometer is most widely used instrument for measuring soil strength. A cone with a base diameter of 20.27 mm was used for the measurement of soil strength (Field Scout SC 900).

Crop parameters

Variety of paddy harvested: An early maturing variety (Pusa Basmati 1509) developed by Indian Agricultural Research Institute has been harvested in all treatment of study.

Heights of stubble before and after combine harvesting: The heights of straw were taken before and after the operation of implements in the combine harvested paddy field.

Amount of loose straw: With the help of 1 m^2 ring, loose straw samples were taken randomly.

Straw load: Twenty samples were taken from one square meter area, and then the average of the weighed sample was converted to quintal per hectare.

Yield: After the operation of straw retention, incorporation and removal technologies, the wheat crop was sown using different sowing methods with the use of different type of machines.

Machine performance parameter

Forward speed: Forward speed of the machine was determined by pole citing method in the experimental field.

Width of machine: Operating width is the width covered by the machine/implement over the field during operation in a single pass.

Field capacity

Effective field capacity: Effective field capacity is usually expressed as hectare per hour (Kepner *et al.* 1978, Aman *et al.* 2020).

$$EFC = \frac{A}{T}$$

Where EFC=Effective field capacity, ha/h; A=Actual area covered, ha; T=Time for covering total area, h.

Theoretical field capacity: It is expressed as hectare per hour and determined as follows (Kepner *et al.* 1978, Aman *et al.* 2020).

$$TFC = \frac{W \times S}{10}$$

Where TFC=Theoretical field capacity, ha/h; W=Width of cut, m; S=Speed of operation, km/h.

Fuel consumption: The amount of refilling required after the test was the fuel consumption for operation and it was expressed as litres per hour.

Time required: Total time required to perform a treatment was calculated by adding the time of each machine that is operated in field for that specific treatment.

Skilled person requirement: Number of humans required to perform the task in a given time.

Economic parameters

Cost of operation:

Fixed cost:

(A) Depreciation- According to the Kepner *et al.* (1978), the annual depreciation is calculated as:

$$D = \frac{C - S}{L \times H}$$

Where D=Depreciation per hour; C=Capital investments (₹); S=Salvage value, 10% of capital investment (₹); L=Life of machine in hours or years; H=Annual use, h/yr.

(B) Interest- The annual interest on the investment can be calculated as (Kepner *et al.*1978).

$$I = \frac{C + S}{2} \times \frac{i}{H}$$

Where I=Interest per hour; i=8% per year.

(C) Taxes and insurance- It may be taken as 1% of the initial cost of the machine per year.

(D) Wages of operator- The operator charged ₹450/day on the basis of 8 h.

Operation cost (Variable cost):

(A) Repair and maintenance (RM) cost-

RM = 2.5% × Purchase price or capital investment per year

(B) Fuel cost-It can be calculated based on actual fuel consumption for the operation.

(C) Lubricants- Average lubrication cost is taken as 30% of fuel cost in ₹/h (Aman 2014).

Total cost of operation per hour: The total cost of operation per hour can be calculated by summation of total fixed cost per hour and total variable cost per hour.

Total Cost/h = Fixed Cost per hour + Variable Cost per hour

Break-even point: It is the ratio of annual fixed cost over difference of profit and total variable cost of the machine.

$$\text{Break-even point} = \frac{\text{Annual fixed cost}}{\text{Custom Hiring profit– Total variable cost}} \times 100$$

B: C ratio: B:C ratio was calculated as (Jaideep 2017):

$$\text{Benefit-cost ratio} = \frac{\text{Gross return (₹/ha)}}{\text{Cost of cultivation (₹/ha)}} \times 100$$

Payback period: The payback period was calculated as:

$$P = \frac{I}{E}$$

Where P=Payback period, years; I=Amount of investment, ₹; E=Expected annual net revenue, ₹.

RESULTS AND DISCUSSION

Soil Parameters: The soil was found sandy loam having 13.8% silt, 16.5% clay and 69.7% sand. Soil samples were taken from the upper 30 cm depth of soil by sieve analysis. The result concluded that the type of soil in the experimental field was sandy loam.

Soil moisture percentage: The moisture content of the upper 30 cm layer of the experimental field at the time of sowing under different treatments was measured on wet basis and it ranged from 12.50–17.27%.

Bulk Density of Soil: The bulk density of the experimental field at the time of sowing was taken for each treatment and it varies from 1.27–1.60 g/cc^3 with an average value of 1.39 g/cc. The coefficient of variance (CV) was measured as 1.05%. The reduction in the bulk density is probably since one or more soil manipulation implements have been used. The incorporation of crop residues resulted in reduction in bulk density and increase in infiltration rate.

Soil Strength: Soil strength of the experimental field at depth of 0–45 cm was measured after the operation of combine harvester by cone penetrometer in kilo Pascal (kPa). Primarily strength increased up to 17.5–20 cm with a highest value of 3663 kPa and then it got reduced. This is due to prolonged settling of particles of soil in shallow field conditions and did not have a significant effect after a certain depth.

Crop parameters

Variety of paddy harvested: The variety of paddy harvested in the field was Pusa-1509, which is a scented variety of paddy crop.

Heights of stubble before and after combine harvesting: Combine harvester with SMS cuts the crop at an average height of 10.1 cm and traditional combine cuts the crop at average height of 43 cm. The percentage reduction in height of straw was more in combine harvester with SMS as compared to traditional combine.

Amount of loose straw: This variation in loose straw (as harvesting of paddy crop was near to the ground surface) was due to the different cutting height of crop (10 cm for combine harvester with SMS and 41 cm for traditional combine) by combine harvesters.

Straw Load: A stubble shaver was operated in the field after the operation of traditional combines. It was due to chopping the standing stubble near to the ground surface, higher amount of loose straw was available in the field.

Yield: After different straw retention, incorporation, and removal technologies, the same variety of the wheat (i.e.) HD 2967 was sown on the field according to different treatments. Minimum yield was obtained under treatment M_7 (54.80 q/ha). The reason for the very low yield of wheat crop in particular treatment may be uneven spreading of wheat seed by manual broadcasting and improper depth of seed placement of wheat seed due to rotavator operation after the manual broadcasting might have affected germination. Maximum yield was obtained under treatment M_4 (70.30 q/ha). The reason may be due to better incorporation of plant

Table 1 Soil and machine parameters under different treatments

Treatment	Moisture content (%)	Bulk density (g/cc)	Fuel consumption (l/ha)	Skilled person requirement (man-h/ha)	Time required (h/ha)
M_1	16.10	1.55^b	22.47^f	9.70	4.18
M_2	13.82	1.56^b	22.29^f	9.98	4.29
M_3	14.28	1.60^a	26.86^e	10.82	4.75
M_4	17.27	1.27^g	53.12^a	14.90	10.39
M_5	13.44	1.35^d	53.05^a	14.34	9.80
M_6	12.50	1.29^{fg}	45.32^c	12.47	7.84
M_7	16.29	1.38^c	46.02^c	10.91	8.14
M_8	14.91	1.32^e	49.52^b	14.07	9.85
M_9	14.41	1.31^{ef}	52.05^a	15.25	11.06
M_{10}	16.52	1.30^{ef}	35.75^d	10.69	6.45
General Mean	14.95	1.39	40.65		7.67
P Value	-	<0.0001	<0.0001		<0.0001
CV (%)	-	1.05	1.82		0.34

The mean values shown with same superscript are not significant among each other whereas the mean values shown with different superscripts differ significantly.

Treatment details given in materials and methods.

residue into the soil which increases water holding capacity and proper growth of crop roots. Better incorporation of plant residue also results in more availability of essential nutrients required for crop. The grain yield in zero tillage was 6% and 10% higher than rotavator tillage and conventional tillage, respectively.

Machine performance parameters

Theoretical and Actual field capacity: Theoretical field capacity and actual field capacity were found lowest (0.37 ha/h and 0.25 ha/h) in reversible MB plough and the highest was found in stubble shaver (1.31 ha/h and 0.99 ha/h). It was because the width and speed of operation of MB plough were less compared to stubble shaver.

Field efficiency: Results shows that the field efficiency of implements varied from 65–88%. Lower efficiency in case of the zero-till drill may be due to chopped straw which resulted in blockage of sowing tynes of zero-till machine. Field efficiency of other machinery was found similar to other studies.

Fuel consumption: There was a significant difference in fuel consumption between the different treatments at P-value <0.0001. Table 1 shows the average fuel consumption of the different treatments. More fuel consumption was found where reversible mouldboard plough (16.50 l/ha) and rotavator (16.57 l/ha) operation were included in the treatment. It is evident from the result that less fuel was consumed in those treatments where direct drilling was done in the field. Minor variation may be due to straw load, compaction ratio, etc.

Time required: A large difference in the time requirement between M_9 and M_1 is due to the fact that more numbers of operations were done in M_9 as compared to M_1 (Table 1).

Economic Parameters

Cost of operation for machine: The cost of operation was minimum in hay rake machine (389 ₹/h, 460 ₹/ha) and maximum was observed in combine harvester with SMS (1898 ₹/h) whereas in straw baler it was observed as (3645 ₹/ha), higher cost of operation of straw baler due to high price of machine. The operating cost of zero-till drill was 1300 ₹/ha. The tillage cost of zero till drill was lower by 89% than the conventional tillage cost. The operational cost for sowing wheat using happy seeder was found 60–70% lower as compared to conventional tillage.

Table 2 Economics of different treatments in comparison with crop yield

Treat-ment	Wheat yield (q/ha)	Treatment cost (₹/ha)	Unit cost of operation (₹/q)	B:C ratio
M_1	62.37	3970	63.67	1.64
M_2	63.47	4018	63.32	1.68
M_3	67.63	4571	67.59	1.50
M_4	70.30	7887	112.19	1.58
M_5	60.20	7511	124.77	1.50
M_6	63.57	6031	94.88	1.79
M_7	54.80	6633	121.04	1.50
M_8	64.20	8730	135.98	1.67
M_9	65.40	9190	140.52	1.68
M_{10}	62.43	4619	73.98	1.80

Treatment details given in materials and methods.

Cost of operation for treatment: The cost of operation was maximum in treatment M_9 (9190 ₹/ha) and minimum was observed in treatment M_1 (3970 ₹/ha).

B:C ratio for machine: This criterion indicates the rate of return per rupee invested on machine. The benefit-cost ratio was found to be highest in Traditional combine (1.99) and lowest in Zero till drill (1.11).

B:C ratio for treatment: The benefit-cost ratio was found to be highest in Treatment M_{10} (1.80) and lowest for Treatment M_5 and M_3 (1.50).

Payback period: It is the period required to recover the initial investment made on machine. The payback period of the machine was found to be minimum in disc harrow (0.33 years), because the initial investment of disc harrow was less among other machine and maximum in straw baler (7.34 years).

Breakeven point: Breakeven point was varied from 41.9 h/yr in planker to 180.51 h/yr in zero-till drill. All the selected machines were found to be economically viable.

Based on the result of study, it can be concluded that wheat yield was found from 54.80–70.30 q/ha, and treatment cost varied from 3970–9190 ₹/ha under different methods of sowing. It is seen (Table 2) that the maximum yield was obtained under the Treatment M_4. However, the cost of operation was high. But the unit cost of operation was highest in the case of treatment M_9. Minimum yield was obtained in treatment M_7 (54.80 q/ha). Benefit-cost ratio was found to be highest in Traditional combine (1.99) and lowest in zero till drill (1.11). Treatment-wise, the benefit-ratio ratio was found maximum in Treatment M_{10} (1.80) and minimum in Treatment M_5 (1.50). Treatment M_3 was a combination of combine harvester with SMS + Happy seeder. The best treatment among the treatments was M_3 due to higher yield and lower cost of operation.

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