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Evaluation of different paddy straw management technologies for their economic viability in rice-wheat system

Amrik Singh, Vandna Chhabra*, Chandra Mohan Mehta, Gurleen Kaur & Sreethu S

Department of Agronomy, Lovely Professional University, Phagwara-144 411, Punjab, India

*Email: vandna.21027@lpu.co.in

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Abstract

The study examines the economics of different paddy straw management methods in rice-wheat systems in Gurdaspur, Punjab during the Rabi seasons (2019-20 and 2020-21). The experiment was carried out with 2 wheat varieties, HD 3086 (V1) and PBW 550 (V2), using varied treatment combinations of crop residue management approaches, tillage and seed drilling methods. Based on the pooled data, the PAU (Punjab Agricultural University) cutter cum spreader + incorporation with Mould Board plough + Use of Seed drill (M4) treatment produced the highest plant height (95.87 cm). Treatment PAU cutter cum spreader + PAU happy seeder with press wheel (M2) (437.71) had the highest density of tillers per square meter, significantly outperforming other treatments. A significant interaction was observed between paddy residue management methods and varieties in terms of the number of tillers. Maximum spike length (12.81 cm) was obtained with Stubble Shaver + Burning + Zero Tillage Drill (M1), whereas maximum number of spikelets per spike (18.33) was noted in method (M2). The treatment method (M2) turned out to be the most efficient in terms of yield (44.02 q/ha) and benefit cost ratio (1.72).

Keywords

Happy seeder, incorporation, productivity, rice, residue management, straw

Introduction

In India, a rice-wheat cropping system has been formed by introducing rice into conventional wheat-growing areas and vice versa (1). In the mid-1960s, Green Revolution technologies led to the emergence of rice wheat as the major production system, covering an area of 29 lakh ha in Punjab, which is called the "food bowl of India". With the rice-wheat system's expansion over the past four decades, several issues have emerged that jeopardize its sustainability. There has been a decline in rice and wheat productivity due to soil organic matter depletion, soil sand overmining and crop residue burning (2). Groundwater in Punjab is declining by 0.6 meters per year. Additionally, excessive fertilizer use, and chemical imbalances have exacerbated the problem of water stress in agriculture and deteriorated groundwater quality and soil fertility (3). In addition to destroying soil fertility, residue burning also contributes to severe air pollution, which contributes to global warming. Farmers burn crop residues to save time and cost, but it causes air pollution and the loss of vast amounts of biomass and plant nutrients, resulting in atmospheric pollution and global warming. It also harms soil properties and soil flora and fauna. Crop residues can also be managed by incorporating them into the soil as livestock feed, biofuel, for the cultivation of mushrooms and for the preparation of biochar. In general, Rice straw is burned by farmers because there is only a 2–3-week window between harvesting paddy and sowing wheat, which makes clearing paddy straw from the fields too time-consuming. The requirement for dry fodder for cattle is mostly met by the wheat straw available sufficiently and supplemented by basmati straw if required. Besides, fodder crops are grown in the sufficient areas in the state. The state's primary objective currently is to increase crop productivity and profitability while properly addressing the issue of burning crop residue or agricultural biomass residue. Additionally, there is an immediate need for an alternative system that is energy, water and labour efficient, helps to maintain soil and environmental quality, and produces more for less cost (4, 5). Sustainability indexes also improve significantly with residue retention (4, 6). Adopting conservation agriculture's guiding principles along with better crop management techniques would increase system productivity and total resource efficiency, boosting the rice-wheat system's sustainability and profitability. In the light of aforementioned considerations, the current study was conducted to examine the different paddy straw management technologies for their economic viability in rice-wheat systems.

Materials and Methods

Experimental site description

A field experiment was conducted with 2 wheat varieties, HD 3086 (V1) and PBW 550 (V2), at a farmer's field in district Gurdaspur, Punjab during the *Rabi* seasons (2019-20 and 2020-21) after harvesting the paddy crop. The site of the experiment was located at 31.96 ^{0}N, 75.23 ^{0}E and an altitude of 265 m. A strip plot design was used with seven treatments that were replicated 3 times for each variety in the field experiment. A combination of conventional and modified straw management, tillage and drilling methods were used as treatments, including M1: Stubble shaver + Burning + Zero Tillage Drill; M2: PAU cutter cum spreader + PAU happy Seeder with press wheel; M3: PAU cutter cum spreader + straw decomposer + PAU happy Seeder with press wheel; M4: PAU cutter cum spreader +incorporation with Mould Board plough + Use of Seed drill; M5: Super Straw management system + Chopper + incorporation + Use of conventional Seed Drill; M6: Straw removal (Manual) + Zero Tillage Drill; M7: Straw removal (Manual) + through tillage + Use of conventional Seed Drill with varieties HD 3086 (V1) and PBW 550 (V2). The machinery that has been used for the management of the straw has been described in Table 1.

Straw decomposer

For the study, a Pusa decomposer (IARI) was employed as a straw decomposer. In this decomposer, the fungal strains responsible for the decomposition of paddy straw aid in boosting the pace of decomposition and are often accessible in capsule form. The decomposer mixture is made by boiling 250 g of jaggery in 5 L of water. Then, add around 50 g of finely powdered chickpea flour. It was then covered with a thin towel and left to ferment for 4 to 5 days in a dry area. This culture was used to further prepare the decomposer solution, which takes around 10-12 days. Around 25 L of decomposer solution are adequate for one hectare of land. It is an environmentally friendly technology that will help to realize the Swachh Bharat Mission.

Table 1. Details of the machinery used for straw management of paddy

Machinery	Specifications
Conventional Seed drill	A seed drill is a device that plants seeds at a specified depth and seed rate. The seeds are taken from the seed box, fed into the seed tube by the seed metering device and covered with soil after they have been sown in the soil.
Happy Seeder	It is an *in situ* technology for managing paddy straws that uses only the part of paddy straw in front of moving furrow openers to manage straw *in situ* and sow wheat seeds into a combined harvested paddy field in one operation (without removing or burning paddy straw). It includes a zero-till drill for sowing wheat and a rotor for handling paddy straw (7). The press wheel attachment was part of the happy seeder machine utilized in this study.
Press wheel attachment	The wheel that presses the chopped straw flung by the flails is attached between two adjacent happy seeder furrow openers/tines. Upon pressing, it creates a uniform layer of paddy straw in the inter-row spaces. In addition to preventing straw from plugging, the rotating press wheels also allow seeds to emerge more quickly. This add-on enhanced the machine's balance and smooth operation, increasing its capacity and effectiveness (7).
Super straw management system (super SMS)	The super straw management system is a method widely adopted in Punjab, where this system is coupled to self-propelled combine harvesters. It was positioned on the back of the combine harvester. The paddy straw from the combine harvester is evenly chopped and distributed.
Stubble shaver machine	The stubble shaver was used to shave standing paddy stubbles. It consists of two blades mounted on a vertical shaft. On all four sides and top, these blades are enclosed in frames.
PAU cutter cum spreader	The "PAU Cutter cum Spreader" is a low-cost, practically usable device for chopping, cutting, and evenly distributing paddy straw in fields of paddy that have been harvested by the combine which prevents farmer from burning paddy straw.
Straw incorporation with Mould board plough	Following paddy harvest, paddy straw is cut with a "Tractor operated Straw mulcher/Straw cutter cum spreader" before being mixed into the soil with a "tractor mounted mould board plough."

It is quite affordable; one kit, which contains 4 Pusa decomposer capsules and can be used to prepare 25 L of decomposer spray, costs only Rs. 20.

Sample Collection

Different growth and yield-contributing factors, such as plant height, tillers per sq. m., spikes per plant, spike length, number of grains per spike, test weight, grain yield and biological yield were noted as the experiment progressed.

Statistical analysis

SPSS software was used to do the analysis, where the differences between mean values were estimated by using a generalized linear model. Duncan's multiple range test was used to find out the most efficient treatment. The least significant difference at the 5% level of significance was used to assess the significant difference between the means.

Results and Discussion

The details of growth and yield contributing factors noted for the experiment, as well as the cost benefit calculation, are provided below:

Plant height (cm)

While the different methods of residue management differed significantly, there were no discernible differences between the varieties or interactions. A maximum plant height of 95.59 cm was observed in M4, and a minimum height of 91.37 cm was observed in method M1. Among the varieties, V2 (94.21 cm) obtained the maximum plant height (Table 2).

Number of tillers/m²

The perusal of data showed that different methods significantly affected the number of tillers per sq. m. According to pooled data, method M2 (437.71) had the most tillers, while method M6 had the fewest (355.65). M2 was found to be statistically at par with M3. There was a significant interaction between the methods of paddy residue management and varieties (Table 2 and Fig. 1). This is likely due to the decomposition of paddy straw, which helps ensure a continuous supply of macro and micronutrients in the required quantities throughout the growth stages of wheat (8). Adoption of the method M2 helps in the timely sowing of the crop, which helps in retaining soil moisture and also facilitates timely operations of crop cultivation. Optimum sowing time is an important factor that determines the growth and yield attributes. Early and timely sowing is one of the most significant conventional techniques for

Table 2. Various growth and yield attributes of wheat for different treatments

Treatments Methods (M)	Plant height (cm)	Number of tillers /m²	Spike length (cm)	No. of spikelet per spike	Number of grains per spike	Test weight (g)
Stubble Shaver + Burning (M1) + Zero Tillage Drill	91.37[c]	369.10[cd]	12.81[a]	15.74[c]	39.52[b]	36.45[d]
PAU cutter cum spreader (M2) + PAU happy Seeder with press wheel	95.11[ab]	437.71[a]	12.13[a]	18.33[a]	44.02[a]	43.75[a]
PAU cutter cum spreader + straw decomposer (M3) + PAU happy Seeder with press wheel	94.35[abc]	427.39[a]	11.32[a]	17.00[b]	43.41[a]	44.75[a]
PAU cutter cum spreader + incorporation with Mould Board plough (M4) + Use of Seed drill	95.59[a]	386.41[b]	10.59[a]	15.75[c]	40.29[b]	41.22[b]
Super Straw management system + Chopper + incorporation (M5) + Use of conventional Seed Drill	94.28[abc]	376.34[bc]	10.36[a]	15.91[c]	39.88[b]	38.09[c]
Straw removal (Manual) (M6) + Zero Tillage Drill	92.20[bc]	355.65[d]	10.47[a]	14.65[d]	39.48[b]	36.68[c]
Straw removal (Manual) + thorough tillage (M7) + Use of conventional drill	92.54[bc]	376.29[bc]	10.34[b]	14.99[d]	37.24[c]	38.09[c]
SEm±	0.411	5.26	0.39	0.19	0.38	0.53
CD at 5%	1.39	14.76	0.63	0.59	1.55	1.61
Varieties (V)						
HD 3086 (V1)	93.06	386.19	10.48	16.09	40.26	39.89
PBW 550 Unnat (V2)	94.21	393.50	11.81	16.01	40.84	39.88
SEm±	0.78	0.78	0.78	0.78	0.78	0.78
CD at 5%	NS	NS	NS	NS	NS	NS
MXV	NS	21.32	NS	NS	NS	2.21

Note: M= Methods, V= Variety

enhancing grain output (9) by improving growth and yield contributing parameters.

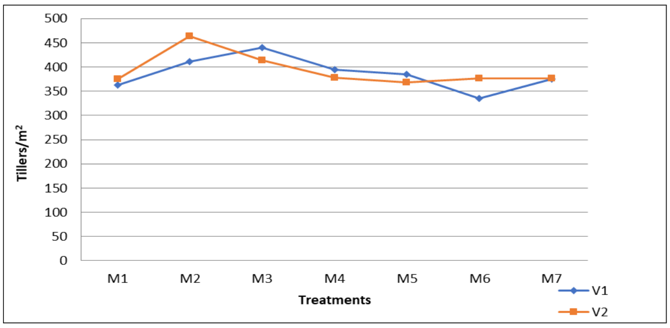

Fig. 1. Interaction between methods (M) and varieties (V) w.r.t pooled data of number of tillers /m^2 in wheat.

Spike length (cm)

The length of the spike serves as a gauge that ultimately affects the number of grains. The maximum length was observed in M1 (12.81 cm). The minimum length was observed in treatment M7 (10.34cm) (Table 2). However, the difference in spike length was non-significant due to the interaction between the different methods of planting and varieties. There was no significant difference between varieties HD 3086 (V1) and PBW 550 Unnat (V2). These results were in corroboration with an earlier report (10) in which spike length was increased with residue retention when compared with conventional methods of planting.

Number of spikelets per spike

Based on the pooled data (Table 2), different methods of paddy residue management significantly affected the number of spikelets per spike. Method M2 had the most spikelet per spike (18.33), whereas method M6 had the fewest (14.65). The results are contrary to the earlier findings (11). Whereas the interaction between methods and varieties on the number of spikelets per spike was found to be non-significant.

Number of grains per spike

Data analysis revealed that various methods of paddy residue management affected the number of grains per spike. Method M2 recorded the highest number of grains per spike, i.e., 44.02 and the lesser number was recorded in method M7 (37.24). A non-significant interaction was found between paddy residue management methods and varieties (Table 2).

Test weight (g)

According to the results (Table 2), the highest test weight was observed in M3 (44.75g) while the minimum was found in M1 (36.45g). However, it was shown that there was a significant interaction between paddy residue management techniques and variety. The results obtained w.r.t. pooled data by varieties HD 3086 (V1) and PBW 550 Unnat (V2) showed the same results on the test weight (g) by adoption M1, M2, M3, M4 and M6 (Fig. 2). The findings are consistent with another report (12), where it was discovered that earlier seeding resulted in improved grain growth and the accumulation of photosynthates due to a longer growing time.

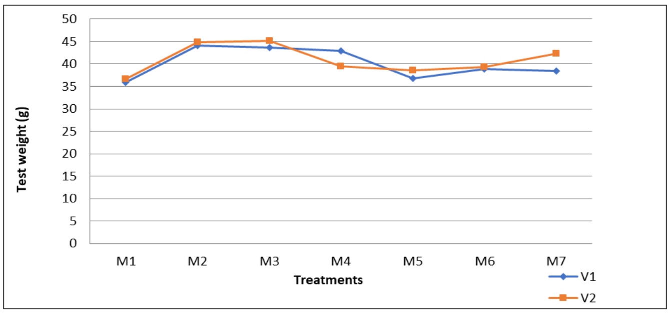

Fig. 2. Interaction between methods and varieties w.r.t pooled data of test weight (g) in wheat.

Grain yield (q/ha)

The highest grain yield was observed in M2 (48.83 q/ha) and was found to be at par with M3 (47.50 q/ha). While the lowest grain yield was observed in M7 (Table 3).

Table 3. Grain yield and biological yield of wheat for different treatments

Treatments	Grain Yield (q/ha)	Biological Yield (q/ha)
Methods (M)		
Stubble Shaver + Burning (M1) + Zero Tillage Drill	44.50^b	90.04^c
PAU cutter cum spreader (M2) + PAU happy Seeder with press wheel	48.83^a	145.09^a
PAU cutter cum spreader + straw decomposer (M3) + PAU happy Seeder with press wheel	47.50^a	126.13^a
PAU cutter cum spreader + incorporation with Mould Board plough (M4) + Use of Seed drill	44.83^b	109.25^{bc}
Super Straw management system + Chopper + incorporation (M5) + Use of conventional Seed Drill	43.50^{bc}	109.97^{bc}
Straw removal (Manual) (M6) + Zero Tillage Drill	43.50^{bc}	101.98^{bc}
Straw removal (Manual) + thorough tillage (M7) + Use of conventional drill	42.16^c	106.40^{bc}
SEm±	0.433	4.09
CD at 5%	2.58	8.38
Varieties (V)		
HD 3086 (V1)	44.76	108.24
PBW 550 Unnat (V2)	45.19	117.05
SEm±	0.78	0.78
CD at 5%	NS	NS
MXV	NS	NS

Note: M= Methods, V= Variety

The retention of residue with the use of a PAU cutter cum spreader functions as fuel for the soil food web and has a significant impact on nutrient cycling for sustaining soil quality and production (13). The combined use of PAU cutter cum spreader + PAU happy seeder with press wheel (M2) also provides additional advantages like reduction in weed growth, conservation of optimum moisture, and maintaining an optimum crop stand by ensuring uniform germination, which ultimately helps in improving the final yield (13-14).

Biological yield (q/ha)

The result of vegetative growth and reproductive yield is biological yield. The higher biological yield in each treatment could have been brought about by the significant effects that residue management strategies had on these characteristics. Among the pooled data, the highest biological yield (145.09 q/ha) was recorded with M2. The biological yield by both the varieties and interactions was found to be non-significant for the pooled data (Table 3). The residual mulching effect of the Happy seeder improves the bio-physio-chemical properties of the soil which results in boosting wheat grain, straw and biological yield (15).

Cost-benefit ratio and economics

Between the treatments, the highest gross return was obtained by the adoption of M2 (Rs. 95788) (Table 4). Gross returns for this sowing technology were superior due to the mulching, which ultimately conserves moisture during the grain filling stage. Though the benefit-cost ratio was also high with M2 (1.72) as compared to M3 (1.67) (Table 3). These results were in corroboration with the findings of (8, 16, 17). The tractor operates under load if the chopper is used as soon as possible after paddy combine harvesting (i.e., 1-2 days after combine harvesting, this period for sun drying of paddy straw). When more time was given in the field after combine harvesting, the paddy straw become difficult to cut and tractor runs got overburdened (18). Thus, it is evident that, as compared to conventional techniques, the Happy seeder minimises the cost of field preparation without compromising the mean wheat yields (19).

Although, the adoption of these systems faces many limitations. Among those, one of the main limitations in the implementation of this approach is due to the varied perceptions of farmers. Even with a 50% price reduction, the narrow window of machine operation, difficulty operating with wet straw, poor machine capacity compared to traditional seed drills, and unavailability of straw shredders are major barriers to widespread adoption. Residue incorporation *in situ* involves more time and effort on the part of farmers. Rice residues can be used in wheat crops to provide a variety of benefits. The direct seeding of wheat in rice residues is made easier by the development of machine such as the Happy Seeder, PAU Happy Seeder, PAU cutter cum spreader, Super Straw management system and PAU Happy Seeder with press wheel. It helps in improving the soil bio-physio-chemical properties, as mulching crop residue with this method helps in the addition of organic matter. This method also provides additional benefits, like maintaining the optimum microclimate for the crop and reducing crop weed competition. Combining PAU cutter cum spreader (M2) + PAU Happy Seeder with a press wheel helps to resolve the seed drill choking problem and non-uniform distribution of seeds, as PAU cutter cum spreader (M2) helps to chop and disperse paddy straw into little pieces, which thereby assures smooth functioning of the seed drill.

Table 4. Cost-benefit ratio and economics of wheat for different treatments

Treatments	Gross return (Rs)	Net return (Rs)	B:C
Stubble Shaver + Burning (M1) + Zero Tillage Drill	88283	34813	1.54
PAU cutter cum spreader (M2) + PAU happy Seeder with press wheel	95788	35250	1.72
PAU cutter cum spreader + straw decomposer (M3) + PAU happy Seeder with press wheel	93615	35063	1.67
PAU cutter cum spreader + incorporation with Mould Board plough (M4) + Use of Seed drill	90258	42813	1.11
Super Straw management system + Chopper + incorporation (M5) + Use of conventional Seed Drill	86703	41563	1.09
Straw removal (Manual) (M6) + Zero Tillage Drill	84333	37313	1.26
Straw removal (Manual) + thorough tillage (M7) + Use of conventional drill	83345	41813	0.99

Note: M= Methods

Conclusion

The current detrimental practice of burning paddy residues in the rice-wheat crop production system can be replaced by several residue management options, which include *in situ* incorporation and removal from the field. It was found that, when compared to alternative residue management methods, wheat sowing with the M2 method produced the maximum number of tillers/m^2, spikelets/spike, number of grains per spike, grain yield and biological yield.

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Authors contributions

AS and VC prepared the research plan and analysis. CMM provided guidelines for the research work and research methodology. GK and SS helped with the writing and proofreading of the manuscript.

Compliance with ethical standards

Conflict of interest: The Authors declare that there is no conflict of interest.

Ethical issues: None.

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