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Evaluation of a Power Driven Residue Manager for No-till Drills

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ABSTRACT

Residue Management Equipment (RME) is developed to cut and remove paddy straw away from furrow openers of the no-till drill. The main operational problem in direct drilling of paddy straw residue is the accumulation and wrapping of loose straw within/on the tines and frame of no-till drills and traction problems with the ground wheel. The equipment consisted of nine parts; each part consisted of two powered wheels, one wheel for cutting the residue and the other wheel for removing them away from no-till drill furrow openers. This equipment was attached with the no-till drill with inverted T type furrow opener and the experiments have been conducted to compare the no-till drill with RME and same no-till drill without RME. No-till drill with RME increased the fuel consumption and time required by 29.6 and 13.14 %, respectively. Adding RME to the no-till drill decreased the amount of residue clogged by 33% and increased the percentage of cut hill from 14.9 to 63.7%. The average numbers of effective tiller, spike length and plant heights were more for no-till drill with RME. Furthermore, the grain yield was increased by 12.4% for fields with no-drill with RME.

Key words: Residue management equipment, direct seeding, paddy straw, powered device, double wheel

INTRODUCTION

Crop residues on the soil surface makes uniform seedling establishment difficult in conservation tillage systems, in addition high levels of crop residues present a constraint to the adoption of conservation tillage because residues mechanically interfere with seeding operations. Improved seeding equipment or residue removal may be necessary for successful direct drilling practices (Carter, 1994; Manjeet and Shukla, 2006; Siemens and Wilkins, 2006).

The collection of straw after paddy harvesting is uneconomical and its end use is not yet wide spread. So either residue is incorporated in the soil or burnt in the field. Incorporation of straw in soil has got some advantages in improving the soil fertility and yield. Many studies suggested that the application of rice residue at a suitable time is crucial for maximizing the beneficial effects of rice residue application. In particular, the increased immobilization process in early stages and the subsequent gradual remineralization allowed plant to utilize nitrogen more efficiently and reduced the pH of the flooded water as compared with mineral fertilizer alone (Ebid *et al*., 2007; Chowdhury *et al*., 2002) . But this process needs many operations which involves both time and money of the farmers and it delays sowing of wheat crop. The wheat production is adversely affected if crop is not sown in time. It has been reported that wheat yield decreases by 35-40 kg ha^{-1} per day, when wheat is not sown before November 30 (Singh and Singh, 1995). An investigation was undertaken to evaluate the impact of different crop residues on different crops yield and organic matter content of soil. The plant height, number of branch/plant, number of pod/plant, number of seeds/pod and seed yield/plant were significantly increased with different crop residues (Alim *et al.*, 2001).

There may be several reasons for delayed sowing but using direct drilling systems can reduce most of those reasons. In addition Indian economy would gain around 1800 million dollar in net present value over the next 30 years from the adoption of no-till in the rice-wheat areas of north-western India (Vincent and Quirke, 2002). The existing practice of storing rice straw, routes of straw losses and problems related to livestock rearing in rural areas were studied. It was identified that majority of the farmers stored rice straw traditionally making stack on the ground in unroofed condition and that caused considerable damage and losses of straw resulting shortage in the availability of rice straw for animals. Farmers reported that straw is lost in three stages-during harvesting, processing and storage condition (Al-Mamun *et al.*, 2002).

Altuntas *et al.* (2006) evaluated the effects of different types of furrow opener and operation speed on soil properties, draft force and percentage of emerged tuber seedling. The draft force requirement of furrow openers increased with operation speeds. Percentage of emerged tuber seedling was between 66.37 and 82.67%, based on furrow opener type and operational speeds. The lowest soil penetration resistance, draft force and high percentage of emerged tuber seedling occurred found with shovel type furrow opener.

In heavy crop residue or when row spacing is narrow, many problems arising and constraining use direct seeding technology (Gupta *et al.*, 2002; Slattery, 1998), causing operator frustration and reducing field capacity. They also tend to cause large clumps of residue to form (Slattery and Riley, 1996) which cover the crop row and choke out young seedlings. Another problem with these types used in drills is that the furrow opening shank disturbs the soil with sufficient force that the uncontrolled soil is thrown out of the seed furrow and occasionally onto the adjacent seed row. This adversely affects seeding depth uniformity which is important for optimum seedling emergence and maximum yield of many crops, including cereals (Chauhan *et al.*, 2000).

Equipment modifications to overcome these problems have included mounting a residue cutting coulter ahead of each furrow opener, increasing the spacing between openers by either increasing row spacing and/or adding ranks of toolbars to improve residue flow, utilizing row cleaning devices to move residue away from the furrow and adding rolling shields next to each furrow opener to reduce soil throw. But many drawbacks include being prone to damage in rocky soils and significantly increasing draft forces and therefore tractor power requirements, they also increase cluttering within the implement frame and therefore promote drill plugging when used in high residue densities (Beri and Sidhu, 1999).

An approach that has not been well explored is the use of powered devices to move the residue. One of existing power residue cutting system is a powered-disc ridge till with no-till planter, it was designed to solve the problems of straw blocking, high energy consumption of strip rototilling and unstable operation on ridges in current no-tillage maize planting in ridge tillage areas of northeast China. The machine used the combined device of powered-disc and depth control wheel to cut the stubble, open seed furrow and stabilize in planting and the key parameters of the device were analyzed and determined. The powered-disc ridge till and no-till planter reduced fuel consumption by 8.5% and soil disturbance by 50%, respectively compared to the strip rototilling ridge till and no-till planter (Wang *et al.*, 2008).

The Residue Management Equipment (RME) was developed on the basis of cutting and removing of paddy straw away from the no-till drill. In order to facilitate the movement of straw, two processes are needed one for cutting the residue and the other for removing them. The significance of the residue cutting include reducing the length of loose straw and cutting stand stable which may be laying in front of no-till drill but still connected with the soil. Removing the residue is necessary to reduce the amount of residue clogged on furrow openers and make the line of sowing clear and clean from residue which affects no-till drill performance. The residue management device was power driven to overcome the problems found with using passive devices (Hegazy and Dhaliwal, 2009).

The design of cutting wheel is based on the idea that using star shape wheel (teeth) would essentially work as a narrow tool but with a forward and rake angle (McKyes, 1985). During soil-wheel contact, the wheel will be provided with greater momentum than that obtained with a smooth, waved, notched and ripple edged which commonly used to cut plant residues, beside reducing the amount of soil throw (Desbiolles, 2004). Besides, the wheel would penetrate the soil more easily and require less vertical force. The toothed wheel will cut the residues only if it penetrates the soil with little depth and rotates. This will happen only if there is enough vertical pressure from the wheel and a corresponding soil resistance to the draught force due to the action of the teeth. This can happen if the wheel was provided by power source to rotate it with specific rotating speed and fixed position.

To adjust the suitable distance between two consecutive teeth, one tooth should touch the residue surface when the previous one penetrate the soil.

For designing the cutting wheel under above consideration, the calculation and assumptions based on standard machine design books were followed. The final geometry of cutting wheel generated by using Solid work design programme and the suitable number of teeth was 12 with 50 mm length for each edge. The removing wheel designed according to the fact that the residue can move away from furrow opener if proper fingers (plugs) operated with suitable angle (the angle between the wheel and the line of travel (Dawn Company, 2001; Yetter Company, 2003). Another concept is that the finger used should be curved, that is help on removing the residue (Siemens *et al.*, 2004).

From pre-laboratory experiments to design present removing wheel, both curved fingers and wheel angle should take in consideration with adjusting the dimensions to attach this wheel with the cutting wheel. The dimensions and the number of the finger used to manufacture the removing wheel were determined according to best results obtained by soil dynamic lab experiments. Both cutting wheel and removing wheel attached together in one unit as double wheel for testing in soil bin.

Keeping the above aspects in view, the study is undertaken to use the developed unit with no-till drill in direct drilling of wheat crop, minimizing the cost by keeping rice straw in field without removing or burning and to evaluate the performance of no-till drill with the inverted 'T' type furrow opener with residue management device in the field.

MATERIALS AND METHODS

Manufacturing the residue management equipment: The workshop experiments were carried out at Department of Farm Power and Machinery, Collage of Agriculture Engineering, PAU University, Ludhiana, Punjab during year 2007-08. During the manufacturing process, the material used in this study collected form departmental stores and local manufacturers and suppliers.

The residue management equipment was consisted of nine parts; each part was consisted of two powered wheels; one wheel for cutting the residue and the other wheel for removing them. The cutting wheel had 300 and 200 mm outside and root diameter, respectively. The suitable number of toothed edges was 12 with 50 mm length for each edge. The circular pitch and Pitch diameter for this wheel were 65 and 250 mm, respectively. The material used to manufacture the cutting wheel was mild steel 4 mm thick. The overall diameter for removing wheel was 280 mm and the number of the fingers used to manufacture the removing wheel was 18 with 50 mm length and 40 mm width. The fingers were curved with 15 degree and spaced equally around its perimeter. An angle of 20 degree (between the line of travel and the fingers) was considered to improve the removing process. The material used for manufacturing the removing wheel was mild steel 4 mm thick. The distance between adjacent fingers was adjusted to avoid accumulation of residue.

The manufactured cutting and removing wheels were attached together with 30 mm spacing between the two wheels. All parts were mounted on one shaft which designed to carry the RME. The shaft was designed after measuring the torque and power requirement and it made from C45 (C45 grade carbon steel) with 60 and 55mm outer and inner diameter respectively. Required RPM for the RME was around 200 RPM. The residue management parts were equally distributed on the shaft with 200 mm between every part (recommended row spacing for wheat).

Attaching the residue management equipment with No-till drill: Attachment of the residue management device with no-till drill done by using a frame had 200 mm length, 450 mm height and 450 mm width. The transmission system mounted on the frame consisted of a speed reduction gear box, main transmission shaft and chain and sprocket drive. The gear box used in the frame had a set of cast-iron bevel gears with 11 teeth on the pinion and 20 teeth on the gear. The transmission system could provide the tractor PTO speed of 540 to 300 rpm for the rotor.

The shaft transmits the power from gearbox to the side drive (chain and sprocket). It is simply supported over two bearings and is welded on one side to the gear. It is 50 mm in diameter and 960 mm in length. The sprocket is keyed to the shaft with the help of a key. The shaft has a step of 7.5 mm on the sprocket side to account for mounting of bearing and The side drive consisted of a chain and sprocket arrangement that transmit the power coming from the gear box via a main transmission shaft to the rotor shaft. The chain and sprocket arrangement was modified to give velocity ratio of 2/3, i.e., it reduces the output to 200 rpm to the rotor shaft. The side drive used with a double strand chain of 30.75 mm pitch and two sprockets with two different diameters.

The roller chain consists of two rows of outer and inner plates. The outer row of plates is known as pin link or coupling link whereas the inner row of plates is called roller link. The pins are press fitted in the pin link and these pass through the bushing which are press fit in the roller links and join these, #80 double strand roller chain has a pitch of 25.40 mm was used. The frame attached to the no till drill then the residue management device attached into the frame.

Experiment technique and field layout: Field experiments were initiated during the year 2007-2008 on the research farm of the Department of Farm Power and Machinery, Punjab Agricultural University, Ludhiana, India. The soil at the experimental area was sandy loam with initial bulk density 1.34 g cm^{-3}. The values of moisture content and cone index were 13.5% and 3.8 MPa, respectively at the beginning of the experiments. Field experiments were carried out in combine harvested paddy field covered with standing stubble and loose straw above the surface without any change. The amount of loose residue found on field surface before sowing varied from

1468 to 3674 kg ha^{-1} for all plots with average of 2535.1 kg ha^{-1}. While the amount of standing stubble found in field surface varied from 1256.3 to 2986.3 kg ha^{-1} with average of 2144.6 kg ha^{-1} for all plots.

The field experiments area was 1104 m^2 divided into 6 plots laid down in randomized block design with three replications for all measurements and four replications in case of yield. Size of each plot was kept 23×8 m. An irrigated wheat (WL-343) variety was sown on November 28, 2007 and the recommended doze of fertilizer and seed rate of 112.5 kg ha^{-1} were applied. The no-till drill used in experiment was 9-row seed-cum-fertilizer drill which consists of frame, furrow opener, seed and fertilizer box, seed and fertilizer metering device and power transmission unit.

Statistical analysis: In field experiment the randomized block design was followed in the study. The experimental data were analyzed statistically. The Analysis of Variance (ANOVA) used by using XLSTAT package and the critical difference at 1 and 5% level of significance was observed for testing the significance of difference between the different treatments.

RESULTS AND DISCUSSION

Fuel and time required: To measure the fuel consumption during the experiments a separate fuel tank with 1 L size was attached above the fuel injection pump. This fuel tank was connected to the fuel line through a connection and another connection was made to this fuel tank to collect the overflow of fuel. The time taken for completion of experiment in each plot was noted down by using a stopwatch. From it the time taken was calculated in h ha^{-1}.

The fuel consumption varied from 10.88 to 11.60 L ha^{-1} for no-till drill with RME. In case of using no-till drill without RME fuel consumption varied from 7.82 to 8.10 L ha^{-1} as presented in Table 1.

The time required varied from 1.89 to 1.96 h ha^{-1} for no-till drill with RME, in case of using no-till drill without RME time required varied from 1.59 to 1.77 h ha^{-1} (Table 1). Statistical analysis showed that the different sowing machine had highly significant effect on fuel consumption with standard deviation 1.85. Also it showed that there was significant effect for different sowing machine on time required with standard deviation 0.15 (Table 1). Using any additional attachment with normal no-till drills will increase the fuel consumption these results similar to results obtained from Manjeet and Shukla (2006) and Beri and Sidhu (1999), where these movable attachments consume more fuel.

Table 1: Effect of various treatments on no. of effective tiller, spike length, plant height, fuel consumption and time taken

Treatments	No. of effective tiller m^{-1} length	Spike length (mm)	Plant height (mm)	Fuel consumption (L ha^{-1})	Time taken (h ha^{-1})
No-till drill with RME (T_1)					
R1	93.08	110.79	886	11.44	1.94
R2	92.73	110.53	886	10.88	1.89
R3	93.17	109.42	886	11.60	1.96
Avg.	92.99	110.25	886	11.31	1.94
No-till drill without RME (T_2)					
R1	87.16	102.97	872	8.10	1.77
R2	86.86	102.46	872	7.82	1.68
R3	86.57	102. 47	872	7.96	1.59
Avg.	86.86	102.63	872	7.96	1.68
SD	3.36	4.19	7.73	1.85	0.15

R1, R2, R3: Replications, SD: Standard Deviation, Av: Average

Clogged residue: The clogged residues are the amount of residue clogged (clumped residue) with the no-till drill or residue management device during sowing operation, this clogged residue is sticking to the wheels causing non-smooth rotations. Surface residue samples were collected before seeding from 1 m^2 area from the field. The dry weight of residue was presented in terms of kg ha^{-1}. Clogged residue during sowing was collected from each opener up to 23 m run, the dried residue, free from soil was weighted and the amount of clogged residue was expressed as kg ha^{-1}.

The total amount of residues clogged under no-till drill with RME varied from 316.4 to 378.6 kg ha^{-1} with 350.6 kg ha^{-1} average. In case of no-till drill without RME the amount of residue clogged varied from 490.8 to 550.2 kg ha^{-1} with 525.5 kg ha^{-1} average. The amount of residue clogged decreased by 33% by using no-till drill with RME compared to no-till drill without RME (Fig. 1). Statistical analysis showed that using no-till drill with the residue manager had significant effect on amount of clogged residue with standard deviation 96.08. This agree with the results obtained by Wang *et al.* (2008) and Desbiolles (2004) at testing new methods for direct seeding.

Cutting standing residue: Standing residues before seeding from 1 m^{-2} area from different locations in the field were noted. Cut numbers of stand stable (hills m^{-2}) were counted from three locations in each plot after running different the treatments. The number of hills recorded in all plots before sowing varied from 22-30 hill m^{-2}. The number of cut hills m^{-2} were observed after sowing and reported.

In case of using RME attached with no-till drill the numbers of cut hills were higher and the average percentage of cut hills varied from 58.32 to 70.04%. Using no-till drill without RME gave percentage of cut hills from 9.10 to 24.08% which was much lower than using no-till drill with RME (Fig. 2). The reason is that using the RME can cut both loose and stands stubble which locates in front of the double wheel and remove them from the way of furrow openers. But in case of no-till drill without RME most of the standing stubbles easily pass between furrow openers without being cut. Statistical analysis showed that using no-till drill with the residue manager had significant effect on cutting standing residue with standard deviation 26.64. Gupta *et al.* (2002) cited that cutting standing residue is difficult by using such types of residue management devices but from this study, the obtained results confirmed that the used attachment can manage the type of residue successfully.

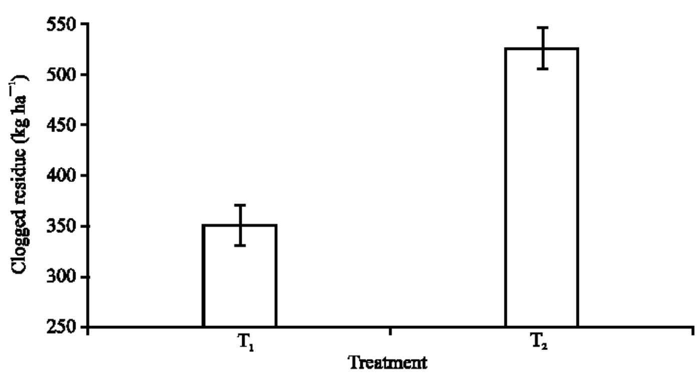

Fig. 1: Effect of using the power driving residue manager on clogged residue. T_1: No-till-drill with residue management device, T_2: No-till-drill without residue management device

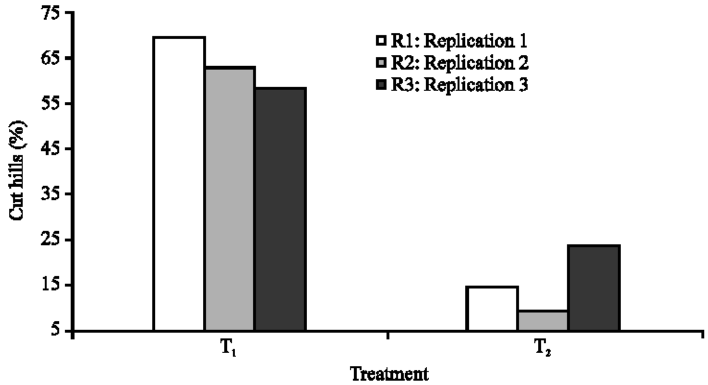

Fig. 2: Effect of using the power driving residue manager on number of cut hill. T_1: No-till-drill with RME, T_2: No-till-drill without RME

Effective tiller count: The yield of the crop will be based on number of effective tillers m^{-1} length. The effective tiller count was measured at harvesting stage from three places of one meter row length in each plot.

Effective tiller count m^{-1} length varied from 92.73 to 93.08 and from 86.57 to 87.16 for no-till with RME and no-till without RME, respectively. The average number of effective tiller was higher in case of no-till drill with RME. Analysis of variance showed that different sowing machines had significant effect on no. of effective tiller per meter length with standard deviation 3.36 (Table 1).

Spike length and plant height: Measurement of spike length for selected plants in mm was done, spike length varied from 109.42 to 110.79 mm and from 102.46 to 102.97mm for no-till with RME and no-till without RME, respectively. The average number of effective tiller was higher in case of no-till drill with RME.

The average plant height is 886 and 872 mm for no-till drill with RME and no-till drill without RME, respectively (Table1). The average plant height was higher in case of no-till drill with RME followed by no-till without RME. Analysis of variance showed that different sowing machines had significant effect on the length of spike and highly significant effect on plant height with standard deviation 4.19 and 7.73, respectively (Table 1).

Grain yield: Manually harvested samples of each 1 m^{-2} were taken from each plot. The weight of each sample (grain + straw) was taken. The samples were threshed with a plot thresher. The threshed grains were weighed and yield per hectare was calculated.

The grain yield varied from 3798 to 5397 kg ha^{-1} with total average of 4593.2 kg ha^{-1} in case of using no-till drill with RME. Using no-till drill without RME gave grain yield varied from 3301 to 4879 kg ha^{-1} with total average of 4024.1 kg ha^{-1} (Table 2). Using no-till drill with residue management device increased the yield by 12.4% more than using no-till drill without RME. Analysis of variance is presented in Table 3 showed that using no-till drill with the residue manager had significant effect on grain yield with standard deviation 337.20. Statistical analysis (Table 3) showed that no-till drill with and without residue management device had highly significant effect on fuel consumption with significant effect on time required. Also there was significant effect on amount of clogged residue, no. of effective tiller per meter length and length of spike, beside, the significance of plant height and grain yield.

Table 2: Effect of various treatments on grain yield

	Grain Yield (kg ha^{-1})				
Treatments	R1	R2	R3	R4	Average
No-till drill with residue management device (T_1)					
P1	5397.00	4894.0	4279	5489.0	5014.8
P2	4824.00	3958.0	5123	4665.0	4642.5
P3	3798.00	4136.0	4014	4541.0	4122.3
Total average	4673.00	4329.3	4472	3898.3	4593.2
No-till drill without residue management device (T_2)					
P1	3496.00	4821.0	4879	3641.0	4209.25
P2	4038.00	3713.0	3971	4330.0	4013.0
P3	3803.00	4137.0	4161	3301.0	3850.5
Total average	3779.00	4223.6	4337	3757.2	4024.1
SD	337.20				

P1, P2 and P3: Plots, SD: Standard Deviation, R1, R2, R3, R4: Replications

Table 3: Analysis of variance (ANOVA) and standard deviation for the variables

Variable	F	Pr>F
No. of effective tiller/m length	226.423	0.004
Spike length (mm)	169.404	0.006
Plant height (mm)	39616.404	<0.0001
Fuel consumption (L ha^{-1})	135.033	0.007
Time taken (h ha^{-1})	6.033	0.145
Clogged Residue	276.575	0.004
Cutting Standing Residue	14.718	0.064
Grain yield (kg ha^{-1})	1.954	0.304

Pr: Probability

The performance of direct seeding technologies was assessed in terms of residue accumulation, fuel and time requirement and crop establishment parameters i.e., plant emergence. In general, results indicated that residue manager gave better plant emergence because machine performed well due to the attached device prior to seeding and the average number of effective tillers was due to better soil-seed environment applied by the attachment. Also, the higher yield due to higher plant emergence as normal result which agree with Siemens and Wilkins (2006) and Manjeet and Shukla (2006).

CONCLUSION

Adding the power driven residue manager as an attachment for no-till drills can increase their ability for working under difficult field conditions. Using this unit under above mentioned experiments decreased the amount of residue clogged by 33% which make sowing wheat in this condition more easily and reduce interface occurred to the no-till drills. Using the residue manager with no-till drill also increased number of cut hill by 76.6% which increase the possibility for uniform sowing in combine harvested rice fields. Effective tiller count, spike length and plant height were high in case of using no-till drill with the residue manager which increased the grain yield by 12.4% more than using no-till drill without this attachment. Although, using this attachment will increase fuel consumption and power required for sowing wheat but it has many features related to crop response and yield which will be more economically and has many benefits for farmers.

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