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DEVELOPMENT OF CROP RESIDUE CUTTING MECHANISMS FOR DIRECT DRILLING UNDER NO-TILLAGE CONDITIONS

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Abstract: *The straw cutting mechanism equipped with plain blade and a pair of twin press wheels assembly was operated on a wide range of straw densities from 3000 to 5000 kg/ha at forward speed of carriage 2.5 km/h and speed ratios 5.20 to 8.67 and evaluated its performance in the soil bin. The experiment of straw cutting mechanism was conducted according to CRD design and Response Surface Method (RSM) was applied to the experimental data using Design Expert statistical software. The relative effect of the variables of speed ratio, pair of press wheels and straw density on the responses of horizontal force (F_h), vertical force (F_v), power consumption, straw cutting percentage and clogged straw were studied. The F_h requirement was observed to be 12.16, 12.50 and 13.59 kgf at 3000, 4000 and 5000 kg/ha straw density, respectively at 5.20 speed ratio and the F_v requirement was observed to be 27.58, 29.91 and 32.82 kgf at the same straw density levels and speed ratios. The power consumption of straw cutting mechanism was estimated to be 192.66, 280.23 and 356.33 W and straw clogged was found to be 7.58, 4.51 and 6.22 kg/ha at the same straw density levels and speed ratios. The quantity of straw cut was found to be 100% for all straw density levels and speed ratios. Similar results were also found at other speed ratios of 6.94 and 8.67.*

Keywords: *No-till, crop residue, surface response method and straw cutting mechanism.*

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INTRODUCTION

Rice - wheat is an important crop rotation and covers an area of 72 Mha in the world and 10 to 12 Mha in India. The total area under no-tillage in the world is 90 Mha and in India it is about 3.43 Mha (Saunders *et al*., 2012, and Tandon, 2007). Due to increase in demand for food production, the farmers have started growing more than one crop a year resulting in land degradation, unsound agricultural practices and increase in use of different inputs such as seed, fertilizer, chemicals and agricultural machinery. In North-Western India, combine harvesting of rice and wheat is now a common practice leaving large amount of crop residues in the fields. the conservation tillage systems, besides the high levels of crop residues do present a constraint for adopting conservation tillage, because the residues mechanically interfere with Crop residues on the soil surface pose difficulty for uniform seedling establishment in seeding operations. Improved seeding equipment or residue removal may be necessary for successful direct drilling practices. The main operational problem in direct drilling of paddy straw residue is the accumulation and wrapping of loose straw on the tines and frame of no-till drills and traction problems with the ground wheel (Hegazy and Dhaliwal, 2011; Graham *et al*. 1986).

Proper seed placement is very important component of the crop production system. No-till seeding requires drills capable of cutting through large quantities of crop residue, penetrating untilled soil, and depositing the seed 25 to 50 mm deep. Problem associated with seed placement under no-till and minimum tillage practices are density, toughness of crop residue and soil penetrating resistance. No till drills have indicated that under heavy crop residues, failures of the disc openers to cut through the residue resulted in the seed being placed either in the residue or on the soil surface. The seed was placed on this trash resulting in poor germination. Since, no-till and minimum tillage system have considerable potential for saving energy, time, man hours, machine hours, controlling wind and water erosion, reduction of soil moisture loss by evaporation, it is extremely important to investigate problems associated with seed placement under crop residue conditions (Kushwaha e*t al*., 1886; Baker and Saxton, 2007). The combine harvested rice-wheat fields are generally left with long loose straw and stubbles in the field which create several operational problems in land preparation for the next crop. Nearly 75% of rice-wheat straw goes as waste besides causing environmental pollution due to straw burning in the field prior to tillage for subsequent sowings. Burning of rice stubbles is widely practiced in Punjab, India, due to a lack of suitable machinery for direct drilling of wheat seed into combine-harvested rice residues. Although direct drilling of seed into burnt stubbles is a rapid and cheap option, and it allows for a quick turnaround between crops, it is causing serious problems for human and animal health due to air pollution, and decline in soil fertility due to loss of nutrients and organic matter (Singh *et al.,* 2008). Considering the problems with direct drilling of wheat into combine-harvested rice fields the study was undertaken to evaluate the performance of straw cutting mechanism under no-till crop residue conditions.

MATERIALS AND METHODS

The research work was carried out in Soil Dynamic Laboratory, Agricultural Mechanization Division, Central Institute of Agricultural Engineering, Bhopal (MP). The experiment of straw cutting mechanism was conducted according to CRD design and Response Surface Methodology (RSM) was applied to the experimental data using Design expert. The relative effect of the variables of speed ratio, pair of press wheels and straw density on the responses was studied. The responses studied were horizontal force (draft), vertical force, power requirement, straw cutting percentage and straw clogged.

The straw cutting mechanism equipped with plain blade was developed for sowing in no-till crop residue conditions in the soil bin system. Parametric software Pro-Engineer creo element was used to design the straw cutting mechanism. Based on the design of plain disc, the whole disc of 460 mm in diameter and 4 mm thick was divided in to eight parts for fabrication of plain eight blades (Fig. 1). These plain blades were fixed on the flange of 350 mm diameter. The flange was made up of mild steel from 4.0 mm thick plate. The bevel angle of the blade was 12°. This plain blade has advantage of replacement of damage or blunt blade instead of complete replacement of whole disc. A pair of twin press wheel assembly was developed to hold and press the straw under tension during cutting of the straw. Press wheel assembly consists of twin press wheel, fork and ratchet returning spring.

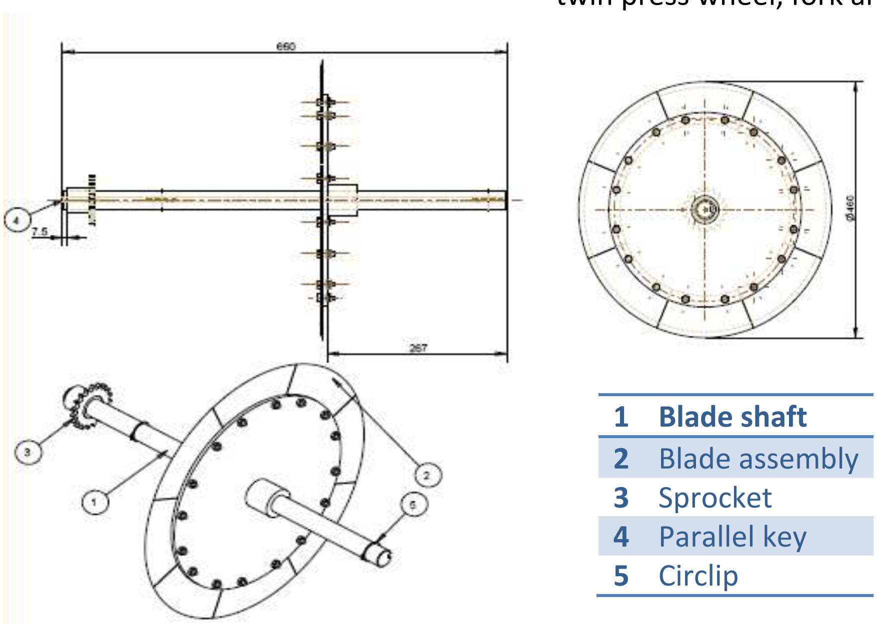

Fig. 1 Plain blade with shaft assembly

The straw cutting mechanism was operated on a wide range of straw densities from 3000 to 5000 kg/ha at carriage speed of 2.5 km/h and at speed ratios 5.20 to 8.67 with a pair of twin press wheels assembly at constant depth of 15 mm. The straw cutting mechanism was fixed on the tool bar provided on the carriage. The carriage was brought and parked over the packed soil and operating depth was set. The tool bar was lowered to the desired depth of penetration from the zero mark. Preparation of straw for an experiment was tedious and time consuming. The paddy straws were taken from the bale for maintaining the uniformity in the all experiments. Pieces of straw of length 400 mm were made and taken for the experiment and maintained the required range of density from 3000 kg/ha to 5000 kg/ha (Mangaraj and Kulkarni, 2010). The carriage motor was set at desired speed of 2.5 km/h. The data acquisition program was run with a data file. Data were collected with straw cutting mechanism running on the straw. Soil force and torque data automatically collected for the working distance of 5 m. Exported the data to MS Excel for further analysis purpose. At the end of the run, the straw cutting mechanism was lifted up and the carriage returned. Collected uncut straw pieces from the soil bin for its measurement of uncut and cut straw percentage and the soil was prepared for the next run.

Simulation of soil conditions in the soil bin was the major factor in determining the performance of the straw cutting mechanism. Various operations such as tilling, wetting of soil, leveling and packing were the part of soil preparation. The soil preparation unit includes roto-tiller, deep working tines, sheep foot roller, soil leveler and water application system to obtain uniform moisture and penetration resistance throughout each experiment with repeatability measures. The field condition of soil compaction level was closely simulated in the soil bin. One Important parameter is soil compactness and this was measured in the field and in the soil bin with a cone penetrologger. Data were collected from fields with a cone penetrologger. Data for soil penetration resistance were collected at seeding time with stubble under no-till conditions on the field of the Central Institute of Agricultural Engineering, Bhopal. Cone index values were evaluated at 0 to 300 mm depth by taking an average of five readings of five different plots.

The core of the complete soil bin system was a computer controlled data acquisition and analysis unit. It was a supervisory control and data acquisition (SCADA) and programmable logic control (PLC) based system. The computer based data acquisition and control system provides on-line display and logging of experimental variables while simultaneously prepares reports in printable format which allows rapid evaluation of experimental results. The experimental design was applied after selection of the ranges. The experiments were randomized in order to minimize the effect of unexplained variability in the observed responses due to extraneous factors. The centre point in the design was repeated six times to calculate the reproducibility of the method. The developed straw cutting mechanism was fixed to the frame provided on front tool bar of the carriage across the bin width. The straw cutting mechanism was fitted on the frame through a sub frame which was entirely supported from the carriage through six appropriately oriented force transducers for measuring the horizontal force, vertical force and lateral force acting on the straw cutting mechanism (Singh *et al.* 2008). The power was given to the straw cutting mechanism from 3.75 kW motor through chain and sprocket arrangement and the torque sensor was coupled to the shaft of the motor. The proximity switch was fitted at the frame of torque sensor's foundation for counting the rpm of straw cutting mechanism. A complete view of experimental set-up of straw cutting mechanism is shown in Fig. 2. The effect of various parameters for development of straw cutting mechanism like pair of press wheels, straw density and speed ratio on horizontal force, vertical force, power required for straw cutting mechanism, straw cutting percentage and clogged straw was measured.

Fig. 2 Experimental set-up of straw cutting mechanism

RESULTS AND DISCUSSION

The soil cone index values of the fields and that of the soil bin were plotted against soil depth and are illustrated in Fig. 3. As expected, the cone index values increased with the depth of soil. There was a greater increase in the cone index from 0 to 100 mm depth in both the cases of field and soil bin. From the Fig. 3 it is depicted that the cone index values for the soil in the field varied from 0.654 to 1.710 MPa at moisture content of 16.68 to 24.76%, whereas, cone index values for soil in the soil bin varied from 0.746 to 1.800 MPa at moisture content of 17.59 to 19.68 **%** and 150 mm depth.

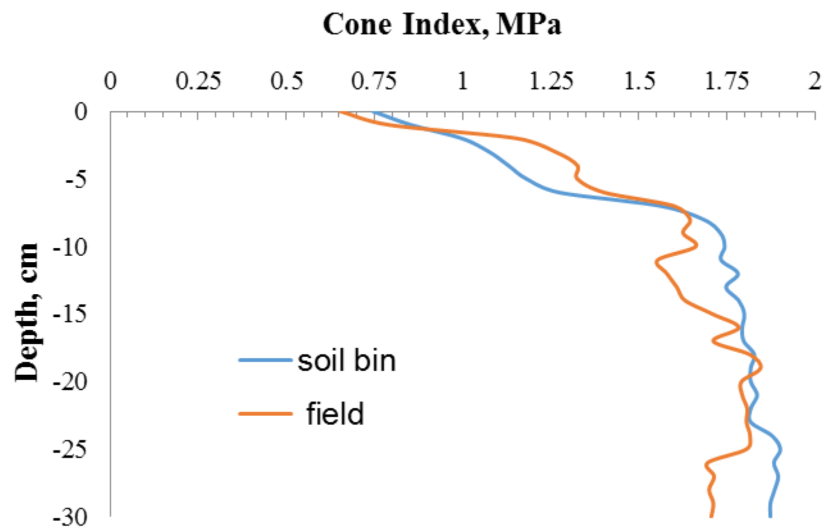

Fig. 3 Average soil cone index values of the field and soil bin

Forces on straw cutting mechanism

From Table 1 it is depicted that the horizontal force (F_h) requirement was observed to be 12.16, 12.50 and 13.59 at 3000, 4000 and 5000 kg/ha straw density, respectively at 5.20 speed ratio. Similar results were also found at other speed ratios of 6.94 and 8.67. Choi and Erbach (1986) reported that an average horizontal force of 20.1 kgf is required for cornstalk residues shearing by rolling coulter at 38 mm depth. The reported higher value of F_h was due to the higher depth of operation of 38 mm and rolling coulter. The Eq. in terms of actual factors can be used to make predictions about the response of horizontal force (F_h) for given levels of each factor. The regression Eq. 1 describing the effects of the variables on horizontal force for plain blade in terms of actual levels of variables given as,

$$\text{Horizontal force} = 2.94 + 0.29\, X_1 + 2.72\, X_2 + 0.0034\, X_3 + 0.26 X_2^{\,2} \qquad (1)$$

Where, X_1- speed ratio, X_2- pair of press wheels and X_3- straw density are the variables

The vertical force (F_v) requirement of plain blade was observed to be 27.58, 29.91 and 32.82 kgf at straw density of 3000, 4000 and 5000 kg/ha, respectively at 5.20 speed ratio and similar trend was observed at other speed ratios of 6.94 and 8.67. The regression Eq. 2 describing the effects of the variables on vertical force for plain blade in terms of actual levels of variables given as,

$$\text{Vertical force} = 6.21 + 0.35\, X_1 + 8.70\, X_2 + 0.0023\, X_3 - 1.27 X_2^{\,2} \qquad (2)$$

Table 1 Horizontal forces and vertical forces on straw cutting mechanism at constant depth of 15 mm

Speed ratio	Horizontal force (F_h), kgf			Vertical force (F_v), kgf		
	at straw density, kg/ha					
	3000	4000	5000	3000	4000	5000
5.20	12.16	12.50	13.59	27.58	29.91	32.82
6.94	12.58	13.68	13.81	28.37	30.94	32.79
8.67	13.24	14.51	14.18	28.85	31.76	35.05

Effect of variables on power consumption, percentage of straw cut and clogged straw

The estimation of power required by straw cutting mechanism with a pair of twin press wheel assembly was found to be 192.66, 280.23 and 356.33W at 3000, 4000 and 5000 kg/ha straw density, respectively at 5.20 speed ratio. Agreement of Kushwaha *et. al.* (1986) for power consumption of powered coulters working at 55 mm depth and at 4000 kg/ha straw density was 173.2 for plain coulter. From Table 3, it is depicted that the 100% straw cutting percentage was observed by plain blade at all the straw density levels of 3000, 4000 and 5000 kg/ha and at all the speed ratio of 5.20, 6.94 and 8.67. It may due to that a pair of twin press wheels assembly was sufficient for holding the straw fitted at both sides of straw cutting blade and plain blade had sooth cutting edge resulted into 100% of straw cutting. Kushwaha *et al*. (1986) also reported that the plain coulter cut the straw nearly 100% at all the rotational speeds and straw densities. The regression Eq. 3 describing the effect of variables on percentage of straw cut in terms of actual levels of variables is given as,

$$\text{Straw cut} = 16.508 + 28.858\,X_2 - 0.008\,X_1^{\,2} + 6.506X_2^{\,2} - 4.39 \times 10^{-9}X_3^{\,2} \qquad (3)$$

Table 2 Power consumption, percentage of straw cut and clogged straw by straw cutting mechanism

Speed ratio	Power consumption, W			Straw cut, %			Clogged straw, kg/ha		
	at straw density, kg/ha								
	3000	4000	5000	3000	4000	5000	3000	4000	5000
5.20	192.66	280.23	356.33	100.00	100.00	100.00	7.58	4.51	6.22
6.94	199.83	284.89	368.60	100.00	100.00	100.00	4.99	3.20	4.01
8.67	203.13	313.57	389.99	100.00	100.00	100.00	5.47	6.27	5.08

Figure 4 shows the straw cutting work performed by the plain blade equipped with a pair of twin press wheels assembly. From Fig. 5, it is seen that, after passing the plain blade the straws were cut and the cut straws were completely sectioned into two halve.

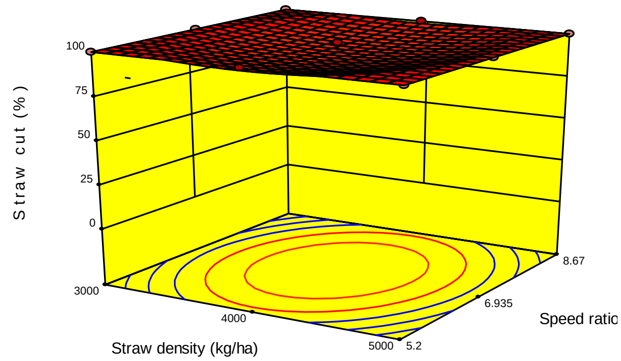

Fig. 4 Effect of speed ratio and straw density on straw cutting percentage by straw cutting mechanism with a pair of twin press wheel assembly

Fig. 5 Straw cutting by the plain blade with a pair of twin press wheels assembly

The amount of clogged straw by straw cutting mechanism with a pair of twin press wheels assembly was observed to be 7.58, 4.51 and 6.22 kg/ha at 3000, 4000 and 5000 kg/ha straw density, respectively at 5.20 speed ratio. Almost similar results were also obtained at 6.94 and 8.67 speed ratios. A very less amount of clogged straw i.e. 4.01 kg/ha was observed in straw cutting mechanism of plain blade with a pair of twin press wheels assembly, it was due to that the a pair of wheels press hold the laid straw properly at the time of straw cutting. A pair of twin press wheel assembly had higher contact area of press wheels with straw and soil surface, and hence almost all the straw were hold by the pressing wheels and resulted into less straw clogging. A very few amount of clogged straw was found and it may due to the 100% straw cutting.

$$\text{Straw clogged} = -20.436 + 21.372X_1 - 54.16X_2 - 0.202X_1X_2 - 1.536X_1^2 + 19.028X_2^2 + 1.244 \times 10^{-8}X_3^2 \quad (4)$$

CONCLUSIONS

The quantity of straw cut by straw cutting mechanism equipped with plain blade and a pair of twin press wheels assembly was 100% for all straw densities (load) of 3000, 4000 and 5000 kg/ha and speed ratios of 5.20, 6.94 and 8.67. The developed crop residue cutting mechanism performed better under no-till conditions and recommended for no-till sowing under heavy crop residue conditions.

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