



Design and development of paddy straw bale shredder

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ABSTRACT

A tractor operated paddy straw bale shredder cum mulcher was designed and developed at Punjab Agricultural University, Ludhiana during 2018–19 to use baled paddy straw as mulch. Mulching reduces weed emergence, increases available water capacity and improves soil properties that results in yield increment. Paddy straw size is generally more than row to row and plant to plant spacing of vegetable crops. Its size was reduced using developed machine. Theoretical design of the machine was followed by development of 3D model and fabrication. The developed machine comprised a shredding rotor for shredding paddy straw bales, a bale drum to handle the bales, a concave grate to control the feeding of bales, a deflector unit for uniform spreading of shredded paddy straw bales and power transmission unit. It has overall dimensions of 1800×1300×1400 mm. The developed machine was run in lab to select operational parameters of the machine. It was further evaluated for mat thickness and uniformity of spread. Effect of forward speed and rotor speed was significant on mat thickness as well as uniformity of spread at 5% level of significance. However, effect of deflector angle on both dependent parameters was non-significant. Mat thickness decreased with increase in forward speed and decrease in rotor speed. Its maximum value was 64 mm for forward speed of 2.7 km/h, rotor speed of 30.7 m/s and deflector angle of 25°. Uniformity of spread was determined using coefficient of variation and its minimum value was 34.38% for forward speed of 2.7 km/h, rotor speed of 30.7 m/s and deflector angle of 25°.

Key words: Bale shredder, Mat thickness, Paddy straw

Paddy-wheat cropping system is one of the most prevalent cropping systems of India. In India about 11 million ha area is under this cropping system (Anon 2014). This system is widespread in Indo-gangetic plains and is widely adopted in states of Punjab, Haryana, Bihar, Uttar Pradesh etc. Paddy cultivation is practised in around 3.07 million ha area of Punjab, India (Anon 2017). More than 20 million tonnes of paddy straw is generated annually in Punjab, out of this farmers burn approximately 15 million tonnes paddy straw in the fields (Anon 2014). The reason behind this trend amongst farmers is the short time window between paddy harvesting and wheat sowing. Major problems related to paddy straw burning are release of pollutants such as particulate matter, sulphur and carbon oxides, besides degradation of soil health. It increases the temperature in the upper 0–2 cm soil layer up to 75°C that decreases the number of soil microorganisms (Tung *et al.* 2014).

Paddy straw can be used as mulch for next season crops like onion and other vegetable crops. Mulching helps in seedling emergence by modification of soil microclimate

and suppresses weed growth (Ghosh *et al.* 2006). Mulching suppresses weed population by action of not allowing the sunlight to reach weed seeds (Talebbeigi and Ghadiri 2012). It reduces the impact of seasonal variations in soil temperature as well as day and night time temperature fluctuations (Lalitha *et al.* 2001). Mulching increases available water capacity by 18–35% and total porosity by 35–46% (Mulumba and Lal 2008). Mulching improves garlic yield and its shelf life (Kabir *et al.* 2013). To use paddy straw as mulch its size has to be reduced by shredding as length of paddy straw is generally more than row to row and plant to plant spacing of transplanted vegetable crop. Reducing straw size will also benefit by decreasing the interspaces between the straw that won't allow the sunlight to reach the weed thus reducing weed emergence. Therefore a machine was designed and developed for shredding the baled straw and spread it uniformly in the field to use it as mulch.

MATERIALS AND METHODS

The present study was carried out at Punjab Agricultural University (PAU), Ludhiana during 2018–19. The materials used and methods including design procedure used in this study has been described under following sub-heads.

Functional requirements of machine: A tractor operated paddy straw bale shredder was required to perform the following functions:

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1. The feeding unit of machine should be able to handle at least one bale and rotate it continuously for uniform shredding of bale(s).
2. Shredding unit should be able to shred paddy straw bales at desired rate to achieve mulching as per recommendation.
3. A concave grate should be able to control the amount of material to be fed.
4. It should achieve requisite spreading of shredded straw in the field for mulching.
5. It should cause minimal damage to the crop while in operation.

Design of components: Theoretical design of components was based on literature cited and functional design requirements of the machine. Design procedure followed for the machine is provided under following subheads:

- a) Machine throughput capacity: The machine was intended to be used for mulching in garlic. Therefore, throughput capacity of the machine was selected as per recommendations for garlic. Mulching rate recommended for paddy residue in garlic is 25 q/a. If a tractor is moving with forward speed of 3 km/h and a 24 kg bale fed into the machine than bale spreading on 1 m wide beds will get consumed in 38 m length in 45.60 seconds.
- b) Throughput capacity of the machine = $(24/45.60) \times 3600 = 1894.73 \text{ kg/h} \approx 2000 \text{ kg/h}$
Determination of power requirement: Misener *et al.* (1990) determined power requirement to shred straw bale of average diameter 1.5 m. The power requirement was 11.8 kW. Therefore, 11.8 kW value was selected for design.
- c) Rotor blades and speed selection: Rotor blades of M shape with serrations were selected (Dhimate 2014). Rotor peripheral speed was selected to be between 30–50 m/s (Thakur 2004). A commercially available rotor used in paddy straw chopper of diameter 285 mm was selected.
- d) Bale drum: Bale drum dimensions were calculated on the basis of bale dimensions. Average bale diameter was 600 mm, assuming 140 mm width flanges to be used in drum and allowance of 20 mm, calculated bale drum diameter was 900 mm. Bale drum height was 800 mm equivalent to width of available sheet in the market.
- e) Gearbox selection: A gearbox of speed ratio 11:20 similar to that of happy seeder was selected for power transmission. Happy seeder runs on a tractor of 50 hp or more. Therefore, this gearbox can easily meet the power requirements of the machine.
- f) Gearbox shaft: Gearbox shaft acted as main shaft and transmitted power from gear box to rotor shaft through belts and sheaves. Main shaft was supported at two positions, one at canter and other at one end of frame thus acted as a simply supported beam. V belt sheaves were fixed at 9 mm from bearing end, hence

bending moment due to them was negligible and thus neglected. This shaft was acted upon by torsional moment only. Power available at main shaft was 23 kW with universal joint transmission efficiency of 0.92 that resulted in torque of 223 N-m by considering backup torque of 7% (As per IS: 12207-2008).

Diameter of main shaft was calculated using

$$T = (\pi \times \tau \times d^3) / 16$$

$$d = 53.38 \text{ mm}$$

Standard shaft of diameter 55 mm was selected.

- g) Rotor shaft: This shaft was acted upon by only twisting force from rotor during shredding. As per Misener *et al.* (1990) power requirement for bale shredding was 11.80 kW that resulted in torque acting on shaft as 76.75 N-m. Calculated rotor shaft diameter was 39.12 mm. However already available shaft of diameter 55 mm was used.

- h) Belts and sheaves selection: Belts and sheaves were selected using Fenner drive design manual. The speed ratio of faster shaft to speed of slower shaft was 1.49. Service factor of 1.4 was selected from drive design manual. As the drive is speed increasing. An additional factor of 1.05 was selected from design manual. Design power of 33.81 kW was calculated using correction factors with power available at main shaft.

A C-section belt was selected for drive using manual. Rated power per belt of 10.44 kW was noted down from table corresponding to the rpm of faster shaft and sheave diameter. Additional power per belt for speed ratio 1.49 was 1.40 kW. Corrected power by taking into consideration additional power per belt and correction factors was 10.1 kW. The calculated belt length was 1854 mm. Number of belts were calculated by dividing design power with corrected power per belt in step. Number of belts for design power came to be 4. However, power required for shredding was 11.8 kW. Considering this power requirement two belts were sufficient to provide required power.

Design of frame: The load acting on the frame was due to weight of all the machine components. Cross section of the frame was calculated considering a and b as outer and inner dimensions respectively of rectangular section. Assuming $a = 1.1b$ and factor of safety for agricultural machinery to be 2, calculated 'a' and 'b' were 47.43 mm and 43.12 mm respectively. A box section with $a = 55 \text{ mm}$ and $b = 50 \text{ mm}$ was selected. A three point hitch system was designed as per IS 4468:1997 under category I for rear mounted type implement hitch system.

Development of 3-D model: A three dimensional (3-D) model of machine was developed using Solid Edge modeling software. It helped in fabrication by providing actual view and working of various components in combination with each other.

Development of tractor operated paddy straw bale shredder cum mulcher: A tractor operated paddy straw bale shredder cum mulcher was developed on basis of theoretical design calculations and functional requirements of the machine. This machine comprised following components:

- a) Main frame: A box shaped frame was used. The frame was made using angle iron of 50×50×3.2 mm. Top end of frame was covered with a 5 mm thick steel sheet. A rectangular pocket of size 745×470 mm was cut in this sheet coincident to the top of rotor casing to facilitate feeding of straw bales.
- b) Shredding rotor: A rotor of diameter 285 mm and length 1050 mm was used. Rotor consisted of 6 rings of 50 mm width and thickness of 5 mm. On the periphery of these rings six steel strips, 1050 mm long, 50 mm wide and 5 mm thick were welded. Nine 'M' shaped serrated blades of size 75×75 mm were mounted on these strips as shredding blades.
- c) Concave grate: The amount of material to be fed to the rotor blades was controlled using concave grate mechanism. In this mechanism arc shaped steel strips 9 mm×21 mm were welded on two steel rods of diameter 20 mm. Hollow steel cylinders having outside diameter 50 mm, inside diameter 22 mm and length 40 mm were used on each end of these rods to provide curvilinear motion. A control lever was provided to adjust the position of arc shaped strips.
- d) Bale drum: A rotating drum was provided to give rotation to the bales. Drum rotation helped in uniform shredding of straw bales fed in the drum. This drum was made using steel sheet of 3.2 mm thickness. Diameter of drum was 900 mm and height 800 mm. A steel strip 9 mm thick and 21 mm wide was attached at 90 mm from drum base to facilitate rotation on restrainers. Another steel strip of 3.2 mm thickness was attached at 80 mm from top to provide strength.
- e) Restrainers: Six restrainers were used to provide rotation to the drum. These were mounted on pins of 150 mm length. These pins were attached to a mild steel sheet of 5 mm thickness.
- f) Deflector: A deflector was provided at the exit of shredding rotor. It helped in uniform spreading of straw with guiding vanes. The deflector angle could be changed by loosening mounting bolts. A set of five vanes was used to guide the straw coming out of the opening. The width of spread was controlled by changing angle of guide vanes.
- g) Power transmission: A gear box having gear ratio 11:20 was used to enhance speed of shredding rotor and change the direction of rotation perpendicular to PTO rotation. Gear box casing was made up of cast iron. V-belts were used to transmit the power from output shaft to the shaft on which rotor was mounted. Another gear box with gear ratio of 15:1 was used to change the direction of rotation and reduce speed to facilitate rotation of bale drum. A flat pulley was mounted on the output shaft of this gear box. A flat belt with idler was used to transmit power from this sheave to drum.

Functional testing in lab to select operational parameters and its evaluation: Functional testing of the developed machine was carried out at PAU, Ludhiana. Initially the machine was operated in stationary position to

select rotor speed. To have intended throughput capacity rotor was operated at various speeds by varying tractor engine rpm and belt-sheave combinations. After this angle of guide vanes mounted on deflector was changed for different levels. The angle of guide vanes for which spread of shredded paddy straw was within 1 m width was selected for field study. The intended forward speed at which machine is to be operated in the field was obtained by operating developed machine on a sheet of length 12 m length. The speed was selected for which appropriate mat thickness with amount of material as per recommendation for mulching was obtained. The developed machine was then run on artificial plants mounted on wooden boards to check whether there is any plant damage or not due to tractor run. Machine was operated in the lab for 10 hr for selection of these operational parameters.

Lab evaluation of this machine was conducted at below mentioned independent variables with three replications each.

- a) Independent variables: Performance of the machine was evaluated at three levels of forward speed (F1= 2.70, F2= 3.10 and F3= 3.80 km/h), three levels of shredding rotor tip speed (S1= 30.70, S2= 36.50 and S3= 41.80 m/s) and three levels of deflector angle (A1= 25°, A2= 30° and A3= 35°).
- b) Dependent variables: The dependent parameters used to evaluate the performance of developed machine in lab conditions were

1) Mat thickness

Mat thickness of shredded paddy straw spread on wooden boards was measured using scale with least count of 1 mm. It was measured at 10 points randomly. The observed readings were averaged out to get average mat thickness.

2) Uniformity of spread

The uniformity of spread for shredded straw was calculated using coefficient of variation (C V). It was determined using frame made using iron strips. A frame of 200×1000 mm was used. This frame was divided into 10 equal compartments of 100 mm width. Five frames were used for each replication. The shredded straw falling in each compartment was collected manually after machine operation in polybags. These polybags were marked for the treatment combinations, frame number and compartment number. These were weighed on an electronic weighing balance.

RESULTS AND DISCUSSION

Specifications of the developed paddy straw bale shredder cum mulcher are provided in Table 1. A 3-D view and developed machine has been shown in Fig 1.

Paddy straw bales used for mulching had moisture content in the range of 9–13%. The rotor peripheral speed selected was 36.5 m/s that was in the range of peripheral speed suggested by Thakur (2004). The angle of guide vanes was made adjustable so that it can be varied according to

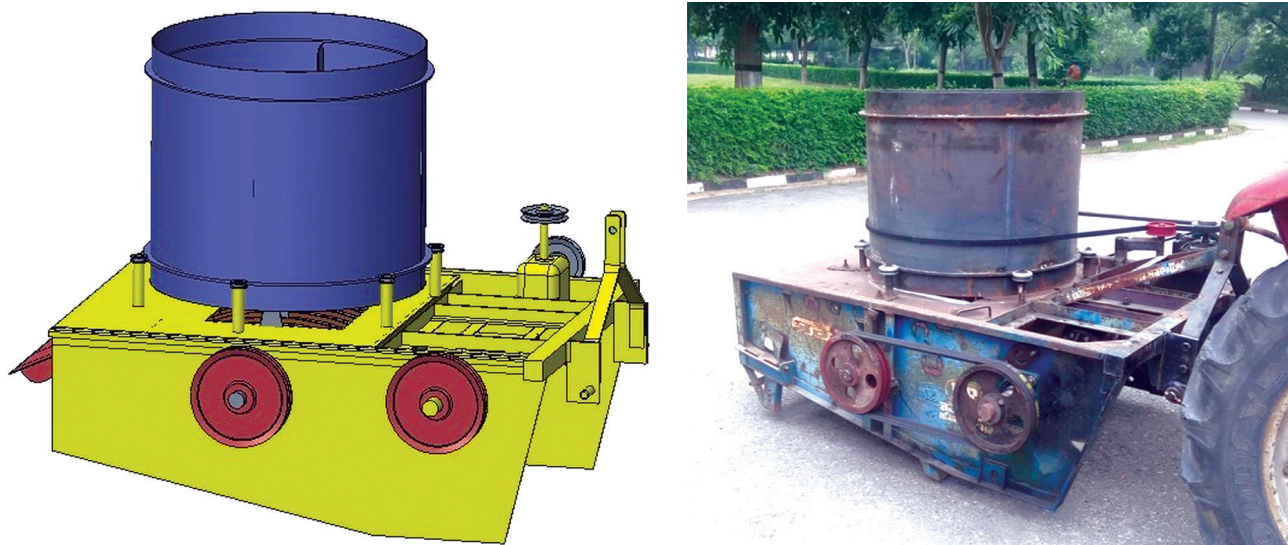


Fig 1 3-D model and a view of developed paddy straw bale shredder cum mulcher.

deflector to get 1m spread. Tractor forward speed with machine was selected as 3.10 km/hr. There was no plant damage observed by tractor with machine run on artificial plants. This machine was then evaluated at selected independent parameters.

Table 1 Specifications of the developed paddy straw bale shredder cum mulcher

Type	Tractor operated
Frame	Box shaped frame
<i>Bale Drum</i>	
Diameter (mm)	900
Height (mm)	800
<i>Restrainers</i>	
Number	6
Type of bearings	Tapered roller bearings
<i>Shredding Rotor</i>	
Number of shredding blade rows	6
Number of blades in each row	9
Number of counter blade rows	2
Rotor tip diameter (mm)	474
<i>Concave grate</i>	
Type	Arc shaped (Adjustable)
Number of iron strips	9 (9 mm×21 mm)
<i>Deflector</i>	
Type	Adjustable
Number of vanes	5 (Adjustable)
<i>Power transmission</i>	
Speed ratio between pto and shredding rotor	1:2.72
Speed ratio between pto and bale drum	26:1
Overall dimensions (mm)	1800×1300×1400

Mat thickness: Analysis of variance revealed that the effect of forward speed (F) and rotor speed (S) on mat thickness was statistically significant at 5% level of significance while the effect of deflector angle (A) was non-significant at 5% level of significance. Interaction of forward speed and rotor speed was significant, while interactions of forward speed with deflector angle and rotor speed with deflector angle were non-significant at 5% level of significance.

Mat thickness decreased with the increase of forward. Mat thickness was maximum at forward speed of 2.7 km/h for all combinations of rotor speed and deflector angle. This may be attributed to the fact that when forward speed was increased same amount of material got spread on longer stretch as compared to the slower forward speed. Hence it reduced the mat thickness of shredded paddy straw. Mat thickness increased with the increase in shredding rotor speed. Mat thickness was maximum at rotor speed of 41.8 m/s for all combinations of forward speed and deflector angle. This may be attributed to the fact that when rotor speed was increased, it increased the amount of material shredded by machine that was reflected in the mat thickness increment.

Uniformity of spread: Uniformity of spread was measured in terms of coefficient of variation (CV). Lesser the value of CV, better will be the performance of machine. Statistical analysis revealed that the effect of forward speed and rotor speed on CV was statistically significant at 5% level of significance. The effect of deflector angle was non-significant at 5% level of significance. Interaction of forward speed and rotor speed was significant, while interactions of forward speed with deflector angle and rotor speed with deflector angle were non-significant at 5% level of significance. CV was affected by the forward speed of the machine. It increased with the increase of forward speed. CV was maximum at forward speed of 3.8 km/h for all combinations of rotor speed and deflector angle

and it decreased with the decrease in forward speed. It was minimum at forward speed of 2.7 km/h for all combinations of rotor speed and deflector angle. This may be attributed to the fact that with the increase in forward speed same amount of material got spread on longer stretch as compared to the slower forward speed. Hence it increased the CV of shredded paddy straw.

It decreased with the increase in shredding rotor speed. CV was maximum at rotor speed of 30.7 m/s for all combinations of forward speed and deflector angle and it decreased with the increase in rotor speed. CV was minimum at rotor speed of 40.8 m/s for all combinations of forward speed and deflector angle. Similar results were reported by Verma *et al.* (2007).

Paddy straw distribution plot: A 3-D paddy straw distribution plot was prepared for treatments combination F1S3A1 having lowest CV value and F3S1A1 with highest CV value to study the distribution of shredded straw for its uniformity. This plot was constructed for all the five compartments with their individual compartment weight. Their comparison showed that along compartments, the shredded paddy straw distribution was more uniform for F1S3A1. Also the amount of material for F1S3A1 was more, that resulted in more mat thickness. Amount of material at center was more compared to sides. This may be due to the fact that during feeding of round paddy straw bale, it remained in contact with shredding blades at the center for longer time as compared to the sides. Therefore amount of material at the sides was lesser as compared to material at the center of the mat.

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