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Performance evaluation of rotary and flail shredders

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ABSTRACT : A large portion of crop residues burnt in farming fields due to non - availability of labour and high cost of residue removal. Burning of crop residues causes environmental pollution as well as increase the loss of plant nutrients. Therefore, appropriate management of crop residues assumes a great significance. Shredders are widely used for shredding the crop residues into small pieces and their performance study is an important factor for wide scale adoption. The field experiments were carried out to evaluate the performance of shredders and estimate the operational cost. The performance of shredders in terms of field efficiency, shredding efficiency was investigated with respect to change in forward speed of operation *viz.*, 2, 3 an 5 km h^{-1} and blade types *viz.*, straight blade and flail blade with selected shredders. The experimental results revealed that increasing shredding efficiency by decreasing in forward speed of operation from 5 to 2 km h^{-1} with optimum peripheral velocity of rotary and flail shredders.

KEY WORDS : Shredding efficiency, Field efficiency, Forward speed of operation, Blade type

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According to Ministry of New and Renewable Energy (MNRE, 2009), Govt. of India estimates, approximately 500 Mt of crop residues generated every year. The unutilized crop residues in India are 84-141 Mt yr^{-1} and these residues burnt on the field due to unavailability of labours, high cost of crop residue removable and unawareness of suitable machinery. The burning of agricultural residues lead to significant emissions of chemically and radioactively important trace gases such as methane (CH_4), carbon monoxide (CO), nitrous oxide (N_2O), oxides of nitrogen (NO_X) and sulphur (SO_X) and other hydrocarbons to the atmosphere and loss of plant nutrients like N, P, K and S (Pathak *et al*., 2010 and Jain *et al.*,2014). Kambis and Levine (1996). Estimated that burning of biomass, such as wood, leaves, trees and grasses - including agricultural waste - produces 40 per cent of carbon dioxide (CO_2), 32 per cent of carbon monoxide (CO), 20 per cent of particulate matter (PM) and 50 per cent of polycyclic aromatic hydrocarbons (PAHs) released into the environment around the globe. Reinhardt *et al*. (2001) analyzed the air quality conditions in a rural town in Brazil (Rondônia) during the prescribed agricultural fire season. They documented that people living in the area are exposed to high levels of smoke for multiple days. The ambient levels of pollutants for particulate matter (PM) for a 24-hour averaged 191 $\mu g\ m^{-3}$ 12.8 ppb for formaldehyde (HCHO), 4.2 ppm for carbon monoxide (CO) and 3.2 ppb for benzene. Some of the compounds present in smoke from biomass are highly irritating. These compounds include acrolein, formaldehyde (HCHO) and aldehydes. Others are potentially hazardous and include carbon monoxide (CO), fine particles (PM), polycyclic aromatic hydrocarbons (PAH's) and benzene (Roberts and Corkill, 1998). Shredders has used for short out the problems of crop residue removal and burning as well as size reduction of crop residue. This will lead to early decomposition of the residue. Incorporation of crop residues into the soil is one method of properly managing crop residues, which will enhance soil health and reduce pollution. Cowlick *et al*. (1971) found that the root sections decomposed slower than other plant parts and concluded that equipment for disposal of cotton residue should include provision for reducing it to a length of 8 to 15 cm and burying it to depth of 10 cm. Roberge *et al*. (1998) evaluated a crop processor in a pull type forage harvester set at 12.7 mm theoretical length of cut which increased energy requirements by 30 per cent in alfalfa and by 7 per cent in corn. Vagadia *et al.* (2004) designed and evaluated an agricultural waste shredder and stated that at the critical speed of cutter head of 50 rpm, more than 80 per cent cut stalk pieces were observed in the length of 15 to 30 and 30 to 45 mm for cotton, castor and pigeonpea crops. Bharambe *et al.* (2002) studied the effect of crop residue incorporation on the physical properties of the soil. Results of the experiments revealed that the application of both cowpea and sorghum stubbles improved physical properties of soil such as decrease in bulk density (1.33 to 1.29 mg m^{-3}), increased infiltration rate (3.88 to 5.10 $\times 10^{-6}$ m s^{-1}) and increased hydraulic conductivity (1.64 to 2 $\times 10^{-6}$ m s^{-1}). Awady *et al*. (1982) reported that rotary disk with cutter blades gave better operation efficiencies. Appropriate tip speeds are determined according to forward speed, blade protrusion and other relevant factors. Eltarhunyl and Fouda (2007) reported that shredder machine was recommended for removing residues of corn stalks at forward speeds between 2 to 4 km h^{-1} and similarly 3 to 5 km h^{-1} forward speed was recommended for self-propelled harvester for removing barley straw. Guzel and Zeren (1990) reported the evaluation of rotary cutters with the peripheral velocity of the blade ranged between 800 to 1000 rpm, respectively. The critical cutting velocity is 15 to 30 m s^{-1}, below which shredding become progressively more inefficient in terms of energy consumptions. Relatively low energy was recorded at 5 to 10 m s^{-1} when stems remained uncut (O'Dogherty and Gale, 1991). High capacity shredders are available and they are advantageous in terms of shredding efficiency and coverage. The performance of each shredder differs depending on many factors. Keeping the above facts in view, the present investigation on performance evaluation of rotary and flail shredders was taken up with following specific objectives:

– To evaluate the performance of available shredders.

– Selecting the optimum conditions for operating the machine.

METHODOLOGY

The field experiments carried out in cotton field in Department of cotton, TNAU (Tamil Nadu Agricultural University, Coimbatore) to evaluate selected shredders under different operating parameters.

Flail shredder :

Flail shredder has knives rotating in vertical plane parallel to direction of travel. The gear box of shredder is receiving 540 rpm from tractor P.T.O. that has converted into 1000 rpm by belt drive. The flail blades used for shredding and it has mounted on rotary shaft in zig zag manner as shown in Plate A. The overall

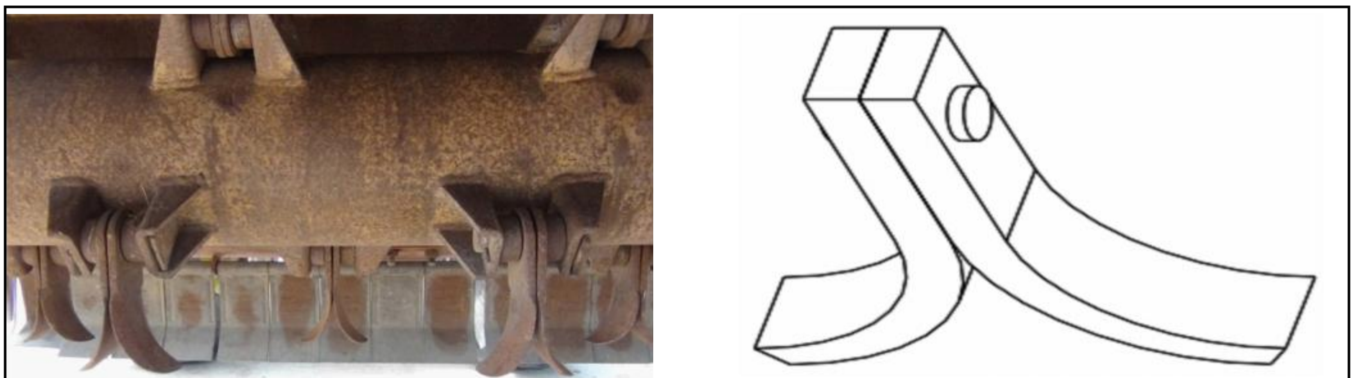

Plate A: Flail blade mounted on center shaft in zig-zag manner

dimension and specification of flail shredder furnished in Table A.

Rotary shredder :

A rotary cutter has knives rotating in a horizontal plane with direction of travel. This shredder is mainly designed for shredding the agricultural crop residues. The straight blade used for shredding and it has mounted on disc in straight way as shown in Plate B. The Rotary shredder gear box receives 540 rpm from tractors PTO; which converted in to 1200 rpm by suitable gear drive. The overall dimension and specification of rotary shredder as furnished in Table B.

Selection of variables :

Performance of impact type rotary cutter depends on many factors *viz.*, shredding blade type, peripheral velocity of rotary blade and forward speed of operation, thickness of blade and rake angle. For achieving maximum shredding efficiency and minimum length of cut of crop stem by various shredder (rotary and flail shredder) were investigated with the following selected variables.

Effect of selected levels of variables in field evaluation:

The field experiments carried out with three levels

Table A : Technical specifications of flail shredder

Sr. No.	Particulars	Dimensions
1.	Rotary shaft length, mm	1600
2.	Axis of rotation	Vertical
3.	No of flail blade on rotary shaft/ line (numbers)	4
4.	Total blades 3 ×4 ×2	24
5.	Diameter of rotary shaft , mm	180
6.	Distance between two flail blades, mm	400
7.	Flail blade length, mm	160
8.	Thickness of blade, mm	10
9.	Width of the blade, mm	60
10.	Speed of rotation of rotary shaft, rpm	1000
Overall dimension		
11.	Length , mm	1650
12.	Width , mm	1300
13.	Height, mm	1200

Table B : Technical specification of rotary shredder

Sr. No.	Particulars	Dimensions
Rotary shredder		
1.	Total length of blade cover distance , mm	1100
2.	Axis of rotation	Horizontal
3.	No of flail blade on shaft/ line (numbers)	2
4	Total number of blades	4
5.	Flail blade length, mm	300
6.	Thickness of blade, mm	10
7.	Width of the blade, mm	70
8.	Speed of rotation of rotary shaft, rpm	1200
Overall dimension		
9.	Length, mm	1400
10.	Width, mm	1340
11.	Height, mm	840

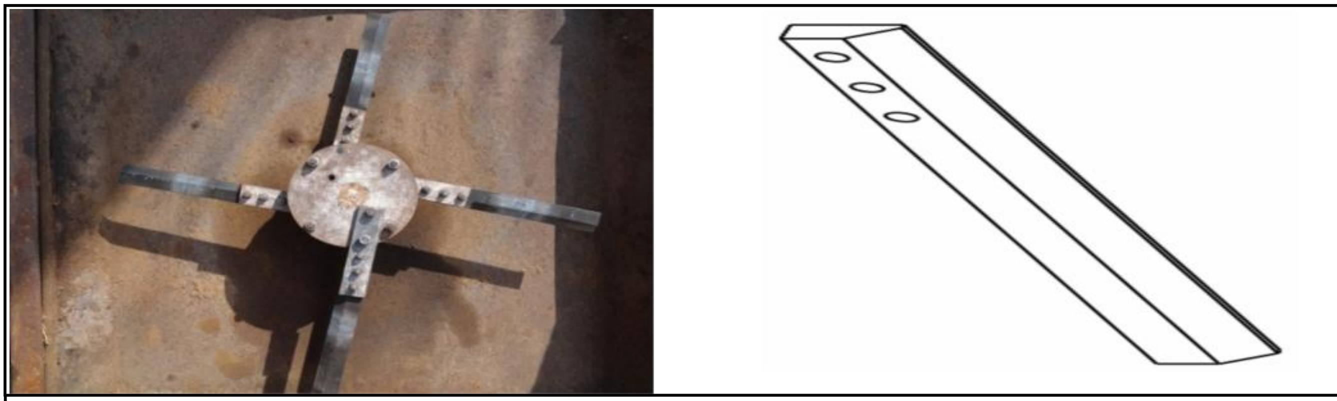

Plate B: Straight blade mounted on disk in straight

of forward speed of operation *viz.*, 2, 3 and 5 km hr^{-1} and two types of blade *viz.*, straight blade and flail blade. The shredding efficiency, field efficiency, cost of operation and length of cut was recorded during the field investigation.

RESULTS AND DISCUSSION

The influences of selected variables on performance of high capacity shredders discussed as follows:

Effects of blade types on shredding efficiency at selected high capacity shredders :

Cutting efficiency is greatly affected by many operating parameters. Adjustment of these parameters caused a serious shredding problem that tends to decreased shredding efficiency and increase the length of shredded crop residues as well as which affect the overall performance of shredders. Representative values of shredding efficiency in terms of length of shredded crop residues versus rotary and flail shredder are given in Fig.1and 2.

Results show that shredding efficiency values increased as the forward speed of operation, reduced from 5 to 2 km h^{-1} of rotary shredder with a straight cutting knife. Data obtained show that reduces the operating speed from 5 to 2 km h^{-1}, increased the shredding efficiency in terms of length of shredded crop residues are least at all selected scale level. Through the flail shredder with flail knife some change as the cutting efficiency because of knives, straight can be shaped to create an updraft which raises lodged material and lifts cut material for further size reduction Kepner *et al.* (1972) . The shredding efficiency of flail shredder has moderately less than a straight knife because of the above mentioned reason similar result was reported by Ahmed and Dosoky (2009).

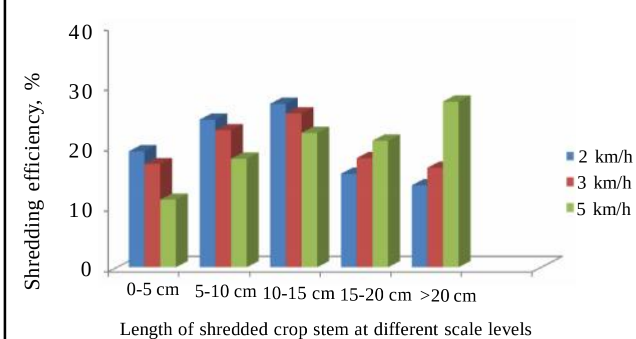

Fig. 1 : Effect of flail blade with different forward speed of operation

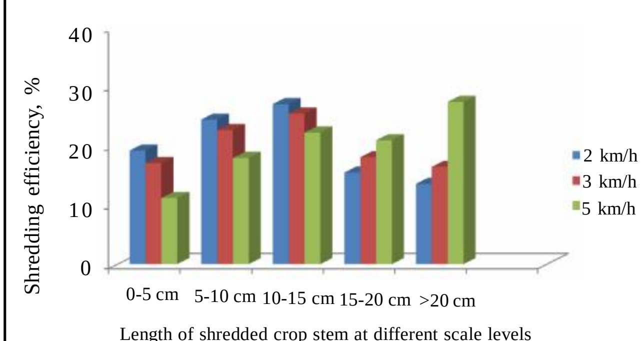

Fig. 2 : Effect of straight blade with different forward speed of operation

Rotary shredder

Flail shredder

Shredded by rotary shredder

Shredded by flail shredder

Plate 1: The view of the trail field before and after shredding operation

Table 1 : Result of performance evaluation of high capacity shredders

Sr. No.	Items	Rotary shredder	Flail shredders
1.	Location	Dpt.of cotton TNAU, Coimbatore	Dpt.of cotton TNAU, Coimbatore
2.	Variety of cotton	KC_3	KC_3
3.	Number of stem per plant	4 to 5	4 to 5
4.	Diameter of cotton stem, mm	12 to 17	12 to 17
5.	Moister content of cotton at the time of shredding d.b %	44.21	44.21
6.	Fuel consumption, lit h^{-1}	2.8	3.51
7.	Operation cost Rs. h^{-1}	2811.23	3147.06
8.	Time required to cover ha h^{-1}	5.29	5.61
9.	Number of un cut cotton stem in row (200 m length)	2	5
10.	Width of operation, m	1.10	1.20
11.	Theoretical field capacity, ha h^{-1}	0.24	0.26
12.	Actual field capacity ha/h	0.187	0.178
13.	Field efficiency, %	77.91	68.46
14.	Shredding efficiency, %	89	84
15.	Save in time compared with conventional method of crop residue removal (%)	78.84	77.84
16.	Save in cost compared with conventional method of crop residue removal (%)	33.85	29.89

Effect of forward speed of operation on shredding efficiency:

The effect of forward speed of operation of cutter blade on shredding efficiency of rotary an flail shredder as shown in Fig. 1 and 2.

This trend is clear from the fact that lower forward travel speed of operation, the time required for conveying crop stem to cutter blade assembly increased which in turn increased the time of impact for cutting crop stem. At forward travel speed of 2 km h^{-1}, it is found that number of cuts per second increased and hence, power and length of cut of crop stem decreased. At higher forward speed it was found that the time taken by conveying assembly to cutter blade assembly is minimum and wedge portion of blade is not coming in contact with stem for clean-cut. So instead of cutting, crushing and shredding of stem took place between the blades, increasing length of cut of crop stem.

Hence, it has concluded that 2.0 km h^{-1} forward travel speeds was most suitable forward speed for shredding the cotton stem for achieving maximum shredding efficiency similar results were reported by Luis *et al.* (1993); Senthilkumar *et al.* (2011); Baiomy (1997); Eltarhunyl and Fouda (2007) and Morad and Fouda (2009).

Field observation during the evaluation of high-capacity shredders :

The result of field evaluation of high-capacity shredders (Rotary and flail shredder) is furnished in Table 1 and the view of the trail field before and after shredding operation as shown in Plate 1.

Conclusion:

Shredding the crop residue by shredders is the only way to control burning of crop residues on field as well control the environmental pollution and improve the soil fertility. When operating a rotary shredder with knife straight and flail shredder with curved knife which corresponded to forward speed of 2 km h^{-1} and peripheral velocity of cutter blade 20 to 30 m s^{-1} was the optimum for achieving maximum shredding efficiency. The selected rotary and flail shredder resulted 33.85 and 78.84, 28.44 and 77.56 per cent savings in cost and time of operation, respectively when compared to conventional method crop residue removal.

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