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Development of double axial transverse rotary mechanism for crop residue cutting, shredding and weeding

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■ **ABSTRACT :** Methods of weeding and crop residue mulch with minimum soil disturbance have greater importance in conservation agriculture. Considering the importance of weeding and crop residue mulch in conservation agriculture point of view the project was envisaged to develop double axial transverse rotary mechanism anticipating that there would be a minimum soil disturbance without compromising cutting efficiency, shredding efficiency and weeding efficiency. The prototype developed and tested at Farm Machinery Research Workshop, Central Research Institute for Dry land Agriculture (CRIDA), Hyderabad during 2016-17. Experiments were conducted with sorghum stalk to finalized critical parts such as blade, rotor length, rotor speed, forward speed for development of prototype. Prototype has two cylindrical rotors having triangular edged tooth plates on its periphery rotating in opposite directions in plane. The rotational speed of cylinders was 450 rpm and suitable for 3 km/h travel speed of tractor. The machine was tested in field conditions for sorghum, maize, castor and red gram crop stem cutting and shredding and weeding. The cutting efficiency of finalized model for sorghum, maize, castor, red gram was found to be 94 per cent, 81 per cent, 72 per cent and 68 per cent, respectively. The shredding of finalized model for sorghum, maize, castor, red gram was found to be 69 per cent, 61 per cent, 46 per cent and 41 per cent, respectively. The performance of prototype in terms of cutting and shredding efficiency was found to be superior for 25 per cent stem moisture compared to 45 per cent and 65 per cent stem moisture and it was true in all the crop studied. The weeding efficiency of newly developed model was comparatively lower it disturbed only one inch soil depth as against 1.5- 2.0 inch soil depth which indicated that the soil disturbance for per unit area was about 33-50 per cent less when weeding was done with newly developed rotary tiller. Overall, the prototype was found to suit the theme of conservation agriculture.

■ **KEY WORDS :** Cutting efficiency, Shredding efficiency, Weeding efficiency, Stem moisture, Crop residue, Rotor speed

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Practice of conservation agriculture is well known in India but its adoption is very low particularly in rainfed agriculture. Weeding and crop residue management are two important aspects in conservation agriculture for which appropriate farm equipment are required. Usually, crop residues can be recycled either by incorporating them into soil for enhancing decomposition or placing on the surface as a mulch. Both practices have advantages and disadvantages but placing crop residues on soil surface is more prioritized in conservation agriculture for maintaining soil health. Secondly, weeding is crucial operation which needs to be removed with minimum soil disturbance. In existing practices, weeds are removed mechanically by hand holes, blade harrows, self propelled power weeder etc. Though there is a large diversity of equipments for mechanical weeding the approach of weed removal method and soil disturbance pattern is more or less similar. Here, weeds are removed along with roots by disrupting top soil layer upto 10-15 cm and windrowed them on the surface between crop rows. Depth of tillage depends on soil condition, type of tools and weed growth. In abroad, removal of weeds through no-till method is also exists, for example, mowing and cutting method. In India, lawn mowers are available with this principle however, its application is limited to small gardens only. The existing method of weeding requires substantial energy and also cost as it involves soil inversion. It is reported that one third of the cost of cultivation is being spent for weeding alone (Rangasamy *et al.*, 1993). The operational energy required for weeding in maize crops under dryland conditions was about 11 per cent (495 MJ/ha) (Dange *et al.*, 2010) of the total energy required for crop production (Mayande *et al.*, 2004). Considering the importance of weeding and crop residue management in conservation agriculture it is felt essential to develop a versatile machine to perform these operations with no or minimum soil disturbance. To achieve this we developed conceptual model using double axial transverse rotary mechanism and it was tested in field condition. This paper highlights detailed design and development of new model. The performance was evaluated in terms of cutting efficiency, shredding efficiency while crop residue mulching of various crops and weeding efficiency while weed removal. The developed model may suit to conservation agriculture.

METHODOLOGY

Concept of double axial transverse rotary mechanism :

The double axial transverse rotary mechanism for crop residue and weed cutting consists of two cylindrical rotors with suitable brush type blades (tooth plates) on their periphery, mounting frame, gear box and prime mover. The difference between existing and new mechanism is that in existing mechanism the plane of axial rotation is in concurrence with plane of forward movement of the machine, whereas, in transverse rotary mechanism the planes of axial rotation of two shafts are perpendicular to the plane of the direction of travel. Out of the two shafts, one is rotated clock-wise and another is anti-clockwise so that it can develop tangential forces and shearing action. It is anticipated that high speed rotary drums along with shearing action and tangential forces can encounter the object (biomass) in contact zone and uplift and/or cut them through clearance given between two drums and windrowed aside. A new mechanism is to ensure to cut the object with no or minimum soil disturbance compared to existing mechanism. The drive for rotating these two rotors is derived from suitable power source through gear box to rotate each shaft individually. The detailed schematic views of existing and new mechanism are shown in Fig. A and B, respectively.

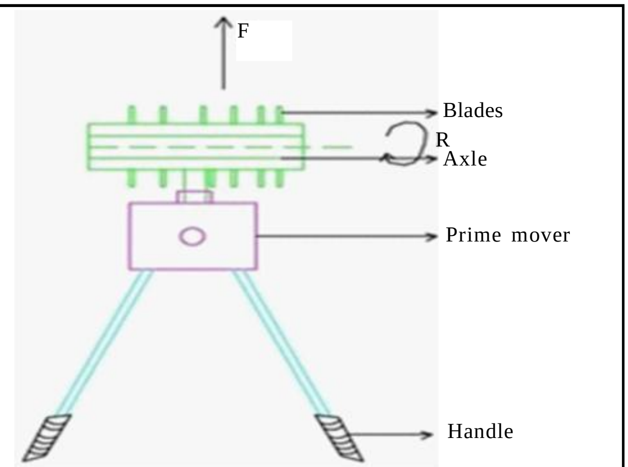

Fig. A : Schematic view of existing rotary mechanism

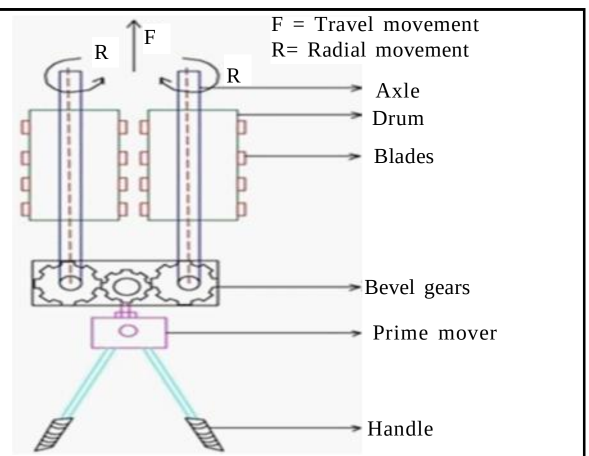

Fig. B : Schematic view of double axial transverse cutting mechanism

Development of machine using double axial transverse rotary mechanism :

The machine consist of main frame, hitch frame, two cylindrical rotors and power transmission. Each cylindrical rotor was of 14 cm in diameter and 35 cm in length made of 12 gauge iron sheet. Tooth plates of triangular shape cutting edge were fabricated and welded on periphery of cylindrical rotor longitudinally. There were four tooth plates on each rotor. The length of each tooth plate is 30 cm. Detailed dimensions of cylindrical rotor along with tooth plates are shown in Fig. C. Two cylindrical rotors are mounted on main frame using pedestal bearing. The central shaft of each cylindrical rotor was fixed with bevel gear to mesh with another bevel gear on main shaft in such a way that appropriate clearance to be obtained between two cylindrical rotors and there should not be overlapping. The rotational power to the cylindrical rotor was derived from PTO shaft through suitable power transmission mechanism to obtain 450 rpm at cylindrical rotor shaft. Diameter of the main shaft and rotary shaft were calculated and found to be 30 mm and 23 mm, respectively. The isometric view of the assembled model of crop residue shredder cum weeder using double axial transverse rotary mechanism is shown in Fig. D.

Diameter of the main and rotor shaft

Diameter of the main shaft $D_s = (16\ XT/\pi\ XS_s)^{1/3}$

Where T = Torque, kg-m, Ss = Allowable shear stress, N-mm, cutting force, F = T/r

T = F X R

Where R = Length of rotor , total forces on shaft are due to cutting force required for crop stalk (f_1) and the weight of rotor (f_2)

For main shaft	For rotor shaft
Hence F = 1.07 + 3 = 4.07 kg	Hence F = 1.07 + 3 = 4.07 kg
T = 4.07 X 0.5 So T = 2.035 kg	T = 1.5 X 0.95 So T = 1.425 kg-m
$Ds=(16 \times 2.035/3.14 \times 1500000)^{1/3}$	$Ds= (16 X 0.95/3.14 X 1500000)^{1/3}$
i.e. = 0190m, safety factor = 1.6	*i.e.* = 0.0169 m, safety factor = 1.4
So Ds=1.6 X 0.0190	So Ds = 1.4 X 0.0169
$Ds=0.0304 \approx 30$ mm	$Ds = 0.023 \approx 23$mm

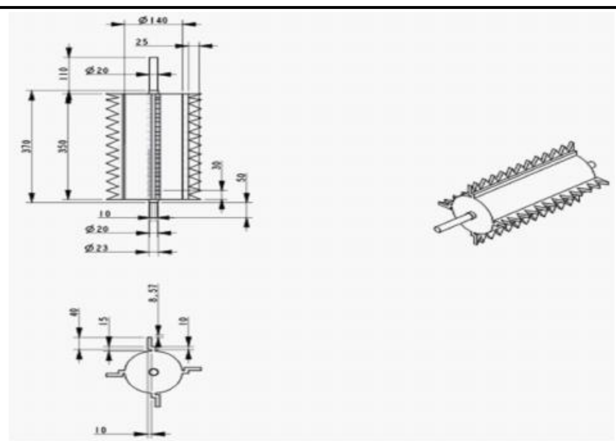

Fig. C : Top view and front view of cylindrical roller with brush type blades (tooth plates)

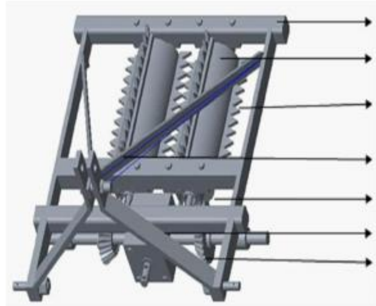

Fig. D : Isometric view of prototype

Testing of developed machine on field :

The developed model was tested and evaluated in terms of cutting efficiency and shredding efficiency for four types of crops namely sorghum, maize, castor and red gram. The cutting, shredding (Adake *et al.*, 2014) and weeding efficiencies (Tajuddin, 2006) were calculated using standard equation. The weeding efficiency was evaluated for dry weed cutting whereas for shredding efficiency the reference chipping length of crop stalk was considered as 8 cm to avoid clogging.

Cutting efficiency	Shredding efficiency	Weeding efficiency, (%)
$= \eta_c = \frac{S_1 - S_2}{S_1} \times 100$	$= \eta_s = \frac{W_1 - W_2}{W_1} \times 100$	$= \frac{W_1 - W_2}{W_1} \times 100$
where, S_1= Number of standing crop stalk above 7.5 cm height before operation, S_2= Number of standing crop stalk above 7.5 cm length after operation	where, W_1 = Weight of total stalk cut (stem) in 50 meter row length before operation, kg, W_2 = Weight of chipped stalk above 8 cm length in 50 meter row length after operation, kg	where, W_1 = Number of weeds counted per unit area before weeding operation. W_2 = Number of weeds counted in same unit area after weeding operation

RESULTS AND DISCUSSION

The results obtained from the present investigation as well as relevant discussion have been summarized under following heads :

Selection of blade for development of a prototype model :

For development of a prototype model a combination of rotor with five types, Rotor 1-Brush type blades with rectangular edge, Rotor 2-Brush type blades with triangular edge, Rotor 3-Brush type blades with crescent moon edge, Rotor 4-Rotor with helical canvas belt and Rotor 5-Rotor only of blades were used for cutting, shredding and weeding operation to identify suitable rotor with blade for desired performance. Results showed in Fig. 1 that Brush type blades with triangular edge (Rotor-2) gave highest cutting efficiency (94%) followed by blades with crescent moon edge (Rotor-3) (89%), blades with rectangular edge (Rotor-1) (85%), Rotor with helical canvas belt (Rotor-4) (45%), Rotor only (Rotor-5) (21%). Results indicated that tooth plates with specific edge provided on periphery of rotor had important role in improving cutting efficiency of sorghum stalk. The triangular edge had more contact with object for which sharing force might have increased and hence resulted into higher cutting efficiency. Result from the Fig. 1 shows that highest shredding efficiency (69%) was recorded by Brush type blades with triangular edge (Rotor-2) compared to all other rotors used for testing. It was observed that trend obtained for shredding efficiency of rollers is similar to the trend of cutting efficiency. Fig. 2 shows that highest (79%) weeding efficiency was recorded from Brush type blades with triangular edge (Rotor – 2) compared to all other rotors used for testing. On the basis of results it was found that rotor with brush type blades with triangular edge perform better and selected for prototype.

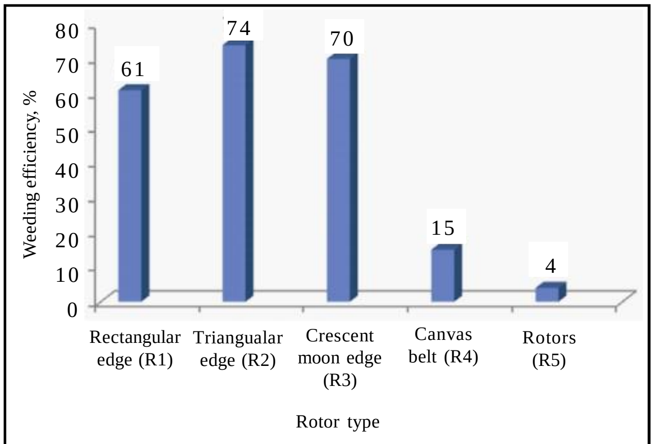

Fig. 2 : Effect of brush type blades on weeding efficiency for Dry weeds

Selection of rotor length for development a prototype model :

For selecting rotor length for development of prototype model three different rotor length *viz.*, 15, 30 and 45 cm were tested. The effect of rotor length on cutting efficiency for sorghum crop stalk is shown in Fig. 3. It is observed that the rotor length had significant effect on cutting and shredding efficiency for sorghum crop stalk. The cutting efficiency for sorghum crop stalk was 88 per cent for rotor length of 30 cm. The relationship between cutting efficiency and rotor length show that rotor length increased from 15 cm to 30 cm increases cutting efficiency with significant variation but length exceed 30 cm to upto 45 cm had no significant variation in cutting efficiency. Based on the result obtained the length of rotor was selected as 30 cm to reduced material

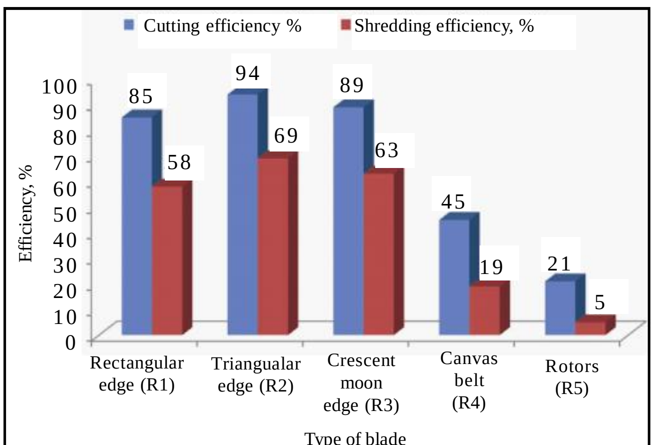

Fig. 1 : Effect of brush type blades on cutting and shredding efficiency for sorghum stalk

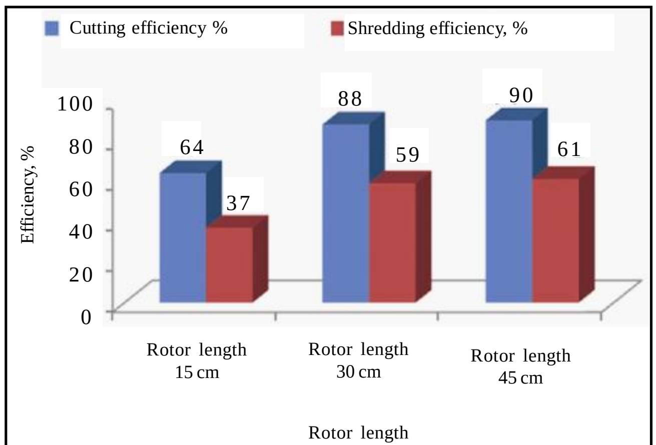

Fig. 3 : Effect of rotor length on cutting and shredding efficiency for sorghum stalk

cost compared to 45 cm without comprising cutting efficiency. The effect of rotor length on shredding efficiency for sorghum crop stalk is shown in Fig. 3. The shredding efficiency for sorghum crop stalk was 59 per cent for rotor length of 30 cm. The relationship between shredding efficiency and rotor length show that rotor length increased from 15 cm to 30 cm increases shredding efficiency with significant variation but length exceed 30 cm to upto 45 cm had no significant variation in shredding efficiency.

The result from Fig. 4 indicated that weeding efficiency for 30 cm length was 74 per cent and it was found far better than 15 cm length. The trend obtained for weeding efficiency is also similar to cutting and shredding efficiency of crop stalk. Based on the result obtained the length of rotor was selected as 30 cm to reduced material cost compared to 45 cm.

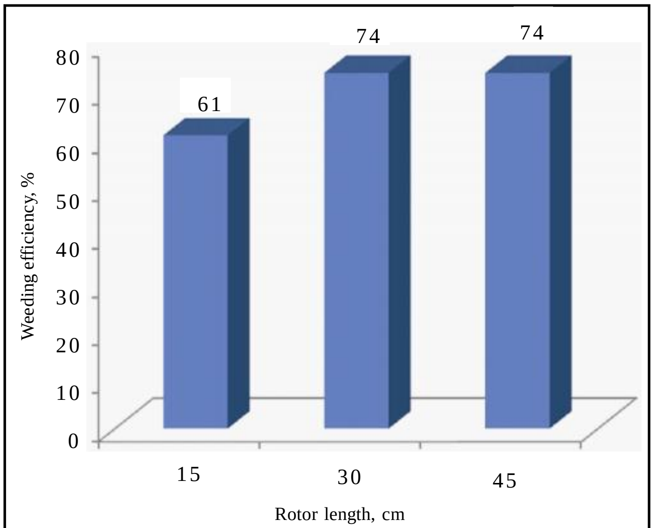

Fig. 4 : Effect of rotor length on weeding efficiency of weeds

Selection of rotor speed for development of prototype model :

Five different rotor speeds *viz.*, 250, 335, 450, 560 and 670 rpm were tested for selection of rotor speed suitable to prototype. The effect of rotor speed on cutting and shredding efficiency for sorghum is shown in Fig. 5 and the relationship between rotor speed and cutting and shredding efficiency for sorghum crop stalk has been developed and presented with polynomial equations. The relationship indicated that cutting efficiency increases with increased rotor speed. During experiment it was observed that rotor speed of 450 rpm was optimum for cutting of crop stalk and the cutting efficiency was found 93 per cent for sorghum at the same speed. The shredding efficiency also increases with increased rotor speed as incase of rotor speed Vs cutting efficiency. The shredding efficiency at speed of 450 rpm was 69 per cent for sorghum crop stalk. So 450 rpm was selected for prototype.

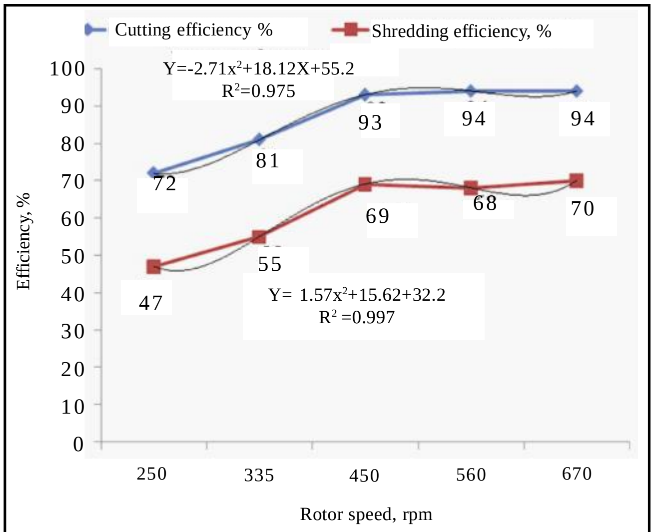

Fig. 5 : Effect of Rotor speed on cutting and shredding efficiency for sorghum stalk

Selection of forward speed for development of prototype model :

For selecting forward speed for development of prototype model five different forward speeds *viz.*, 1, 2, 3, 4 and 5 km/h were tested. From Fig. 6 it has been observed that cutting efficiency was increased when forward speed increased from 1 km/h to 3 km/h, however, the variation in cutting was very close. The relationship of forward speed and cutting efficiency was fitted positively to polynomial equation with R^2 =0.96 and above. The highest cutting efficiency of 91 per cent at 3 km/h was recorded for sorghum crop stalk. On the other hand the shredding efficiency was decreased with increase in forward speed. It was noticed that variation in shredding was close when forward speed increased from 1 km/h to 3 km/h, further increase in forward speed had substantial variation. The shredding efficiency was drastically reduced after 3 km/h which attributed less retention of crop residue in contact zone with rotary cylinder. The relationship between forward speed and shredding efficiency was negatively fitted to polynomial equation with R^2 =0.97 and above. The highest shredding efficiency was found as 69 per cent at 3 km/h for sorghum crop stalk.

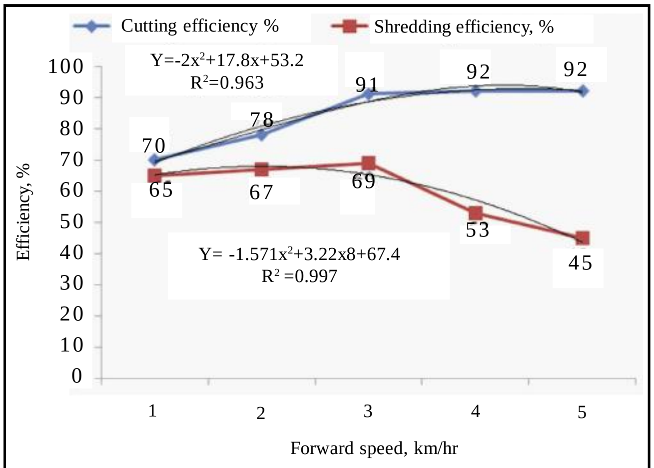

Fig. 6 : Effect of forward speed on cutting and shedding efficiency for sorghum stalk

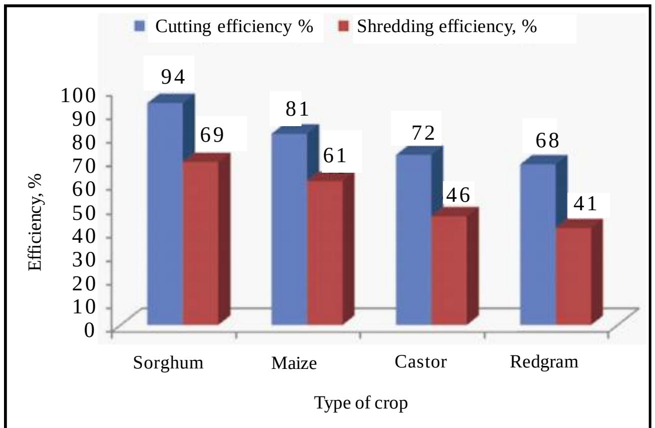

Fig. 7 : Effect of forward speed on shredding efficiency

Performance of developed model :

The machine consist of main frame, hitch frame, two cylindrical rotors and power transmission. Each cylindrical rotor was of 14 cm in diameter and 35 cm in length made of 12 gauge iron sheet. Tooth plates of triangular shape cutting edge were fabricated and welded on periphery of cylindrical rotor longitudinally. The length of each tooth plate is 30 cm. Rotor speed 450 rpm and finally forward speed 3km/hr. The performance of the prototype was evaluated for cutting and shredding efficiency of four types of crops namely Sorghum, castor, maize and red gram in CRIDA farm, Hyderabad. The highest cutting efficiency (94%) was recorded with sorghum and lowest (68%) was in red gram crop. The shredding efficiency was also highest in sorghum crop (69%) and lowest in red gram crop (41%). The cutting and shredding efficiency is one of the important parameter to judge the performance. Amongst different crops the performance of cutting and shredding efficiency (Fig. 7) follows the trend: sorghum>Maize>Castor>Red gram.

The weeding efficiency was assessed on weeds after different day's *i.e.* 10, 20 and 30 days weeds. It was observed that weeding efficiency increased with the age of weeds. The weeding efficiency of newly developed machine was 61 per cent for 10 days old weed, 69 per cent for 20 days old weed and 71 per cent for 30 days old weed (Fig. 8). The performance of developed model was also compared with traditional method of weeding *i.e.* use of rotary tiller. Fig. 9 shows the weeding

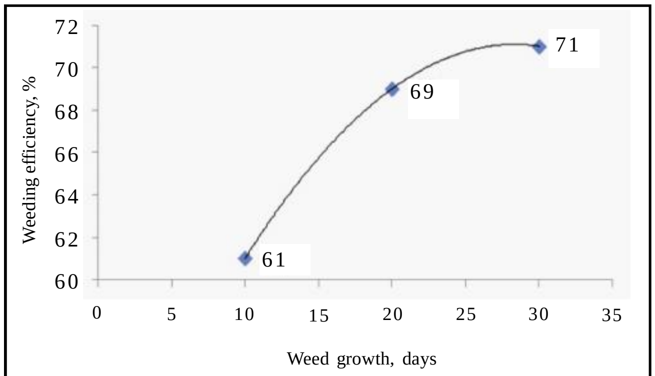

Fig. 8 : Effect of weed growth on performance of machine

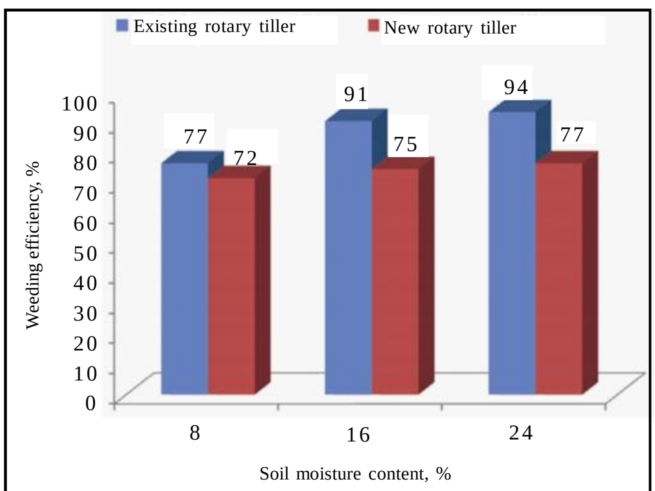

Fig. 9 : Comparative performance of existing rotary weeder and new prototype

efficiency of existing rotary tiller (77%) and newly developed model (72%) at 8 per cent soil moisture level was closely varied. However, efficiency of existing rotary tiller at 16 per cent and 24 per cent were 91 per cent and 94 per cent compared to 75 per cent and 77 per cent weeding efficiency of newly developed prototype for corresponding soil moisture. The weeding efficiency of newly developed model was comparatively lower and similarly the soil disturbance per unit area was also low which is desirable for conservation agriculture. It was found that soil disturbance was only one inch soil depth as against 1.5- 2.0 inch soil depth with rotary tiller which indicated that volume of soil disturbed per unit area was 33-50 per cent less with new weeding mechanism.

The effect of stalk moisture content on cutting and shredding efficiency for sorghum, maize, castor and red gram is shown in Fig. 10 and 11. Result shows that the cutting and shredding efficiencies were dependent on moisture of crop stalk. Higher the moisture lesser would be cutting and shredding efficiency, this was due to higher cutting force required for crop stalk containing higher stalk moisture there is an inverse relation between stalk moisture and cutting force (Swami, 2017).

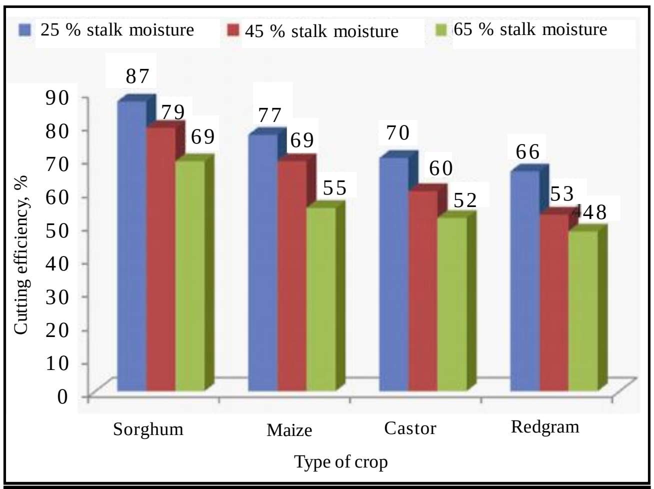

Fig. 10 : Effect of stalk moisture on cutting efficiency

Conclusion :

A prototype model based on double axial transverse rotary mechanism with triangular edge, rotor length of 30 cm and rotor speed of 450 rpm was successfully developed for crop residue cutting, shredding and weeding operation. The performance of the prototype was found

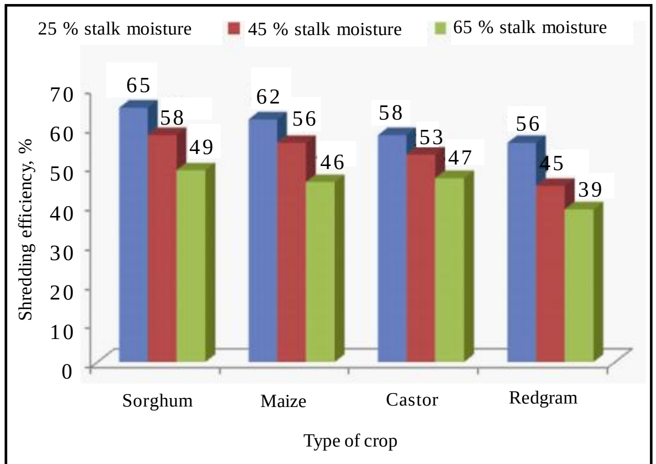

Fig. 11 : Effect of stalk moisture on shredding efficiency

better for sorghum stalk followed maize, castor and red gram.

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