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Modifications and Development of Critical Components of Rotary Tiller for Improving Biomass Incorporation Efficiency (*In-situ*) in Dryland Situations

R.V. Adake, V.M. Mayande, I. Srinivas, B.S. Reddy, C.R. Thyagaraj and A.C.S. Kumar[1]

Central Research Institute for Dryland Agriculture, Hyderabad-500 059, Telangana
[1]Jawaharlal Nehru Technological University, Hyderabad- 500 072, Telangana

Email: rvafmp@gmail.com

ABSTRACT: Biomass incorporation in soil, though beneficial is not widely adopted by farming community due to non-availability of suitable machines. The present study is an improvement over the existing model of rotary tiller through introduction of three mechanical interventions *viz.,* (i) eight sets of rotary blades with critical bending angle, (ii) 1200 mm long compression reel ahead of rotar assembly and, (iii) discs. Both modified and existing models were tested for *in-situ* incorporation of legume crops. It showed that with modified rotary tiller, incorporation efficiency increased to 80, 86 and 72% from the earlier 54, 60, and 44% in case of cowpea, horsegram and sunhemp crops, respectively. Chopping efficiency increased to 81, 78, and 69% from the earlier 38, 32 and 21%, respectively with these crops. Both these models were tested at 5 soil moisture content levels *viz.,* 6,12,18,24, and 30% to determine the moisture level for obtaining maximum efficiency. Results showed that maximum efficiency of rotary tiller was attained at 18% of soil moisture. These machines were also tested under two soil types i.e. Alfisols and Vertisols. Higher efficiency of rotary tiller registered in Alfisols than Vertisols. It was concluded that design modifications of critical components in rotary tiller resulted in greater performance on improving biomass incorporation efficiency.

Key words: Biomass, rotary tiller, compression reel, incorporation efficiency and chopping efficiency

In-situ placement of green manure crops and crop residue (twigs, leaves and thin stems, husk etc.) in top layers of soil and covering them suitably with a soil layer to the possible extent is known as 'Biomass Incorporation'. Design of biomass incorporation tools is of great concern for improving quality incorporation. Depth of placement, type of biomass, time of incorporation and other soil and crop related parameters are to be taken in to account while designing the biomass incorporation tools. Tarafdar *et al.* (2001) reported that best result could be expected if well chopped biomass is incorporated in productive soil zone with uniform mixing. Placing longer stalks on or near the surface does not help biomass decomposition (Schomberg *et al.,* 1994).Very few suitable machines are available for this purpose but their efficiency is low. Rautary (2004) reported that direct operation of rotary tiller was found to be about 47% energy efficient and 42% cost effective but it had lesser degree of incorporation of chopped straw (33%) compared with MB plough and rotary tiller combination. Ram *et al.* (1980) noticed that incorporation of stubbles with L-blade rotary tiller was about 40% and provided good soil texture.

Conventional rotary tiller can incorporate crop residues like cereal and pulses stubbles and are more suitable to them. Its efficiency reduces in case of incorporation of cover crops like sunhemp, cowpea and horsegram etc. (commonly grown as green manure crops for soil incorporation in many parts of India). The cutting process is different and needs different design approach for *in-situ* biomass incorporation than that of for soil tillage. More important where biomass has to be incorporated *in-situ*. The height of the crop is major limiting factor for cutting of biomass. Adake *et al.* (2010) observed that chopping efficiency of rotary tiller was of the order of 28-38% for different green manure crops. They further reported that existing rotary tiller encountered entanglement (wrapping) of moist and flexible crop stems leading to poor performance. The entanglement is due to lack of firm grip and poor interactive grip between biomass and the rotary blade.

Hence, the aspects of configuration of rotary blades for maximum cutting, configuration of rotor to reduce entangling, and other possible attachments for increasing interaction between blade and biomass were taken up and was studied in order to improve overall efficiency of rotary tiller for biomass incorporation. The rationale behind the designing of incorporation tools for effective incorporation and faster decomposition is to uproot the biomass completely from the soil, chop it properly with optimum reduction, and place them below the surface or cover the soil uniformly so that it is not exposed to direct heat. An attempt has been made in this paper for (i) developing critical components of rotary tiller, (ii) testing of newly developed rotary tiller in dryland conditions and, (iii) assessing its performance in terms of incorporation efficiency and chopping efficiency. This machine was also assessed for suitability under six levels of soil moisture conditions and two types of predominant soil types.

Materials and Methods

Design, development and fabrication of (i) rotary blade with critical bending angle (ii) compression reel to press the biomass ahead of rotary tiller and (iii) disc were carried out in Farm Machinery Research Workshop at Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad.

Fabrication of rotary blades

The commonly used rotary blades are of 'L' shape having 90^0 bending angle of chord at cutting edge. It is known that increase in bending angle of chord at cutting edge improves the cutting action of biomass and also the soil stir. After running and assessing its performance at three bending angles of 90^0, 105^0 and 120^0, the angle that reflected maximum incorporation was chosen and it was 105^0. Detailed design of L shape horizontal chord with 105^0 bending at cutting edge angle is given in Figure 1.

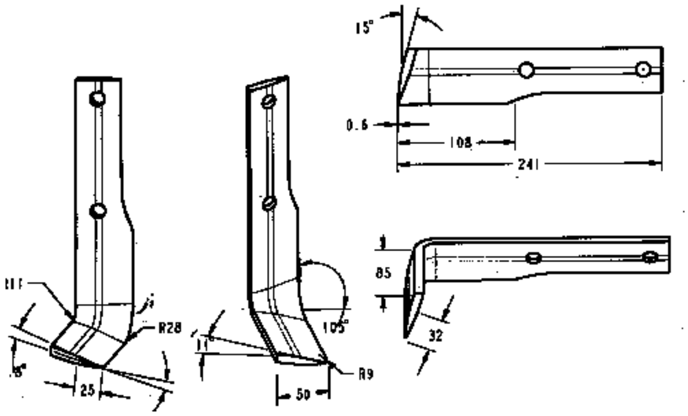

Fig. 1 : Schematic view of L blade of horizontal chord with 105^0 bent

Fabrication of compression reel

The compression reel of 1200 mm long having twelve blades being fixed on periphery of the circular plate of 150 mm diameter was fabricated, and is shown in Figure 2. The reel assembly was rested on central shaft through welding. The length of compression reel was kept equal to effective width of rotary tiller (1200 mm). Compression reel was fixed ahead of rotor assembly of rotary tiller using extended frame (Plate 1).

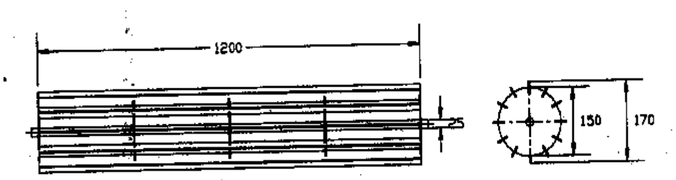

Fig. 2 : Schematic view of compression reel

Fabrication of rotary discs (7 Nos.) for two tier cutting

Design specifications of disc blade are shown in Figure 3. The mild steel (MS) sheet of size 360 ø (mm) with 3 mm thickness was chosen for disc blade. Sheet was cut into two halves and each half was sharpened at its peripheral edge to obtain 16^0 sharpening angle. Each half blade was cut at its center so that two symmetric halves could be fixed on central shaft by obtaining diameters of 100 ø (mm). Two halves of blades were fixed on central shaft of rotary tiller along with L-blades with suitable clamps. Seven such blades were fabricated all of same size and type and was fixed on rotor shaft along with L-blade as shown in Plate 2.

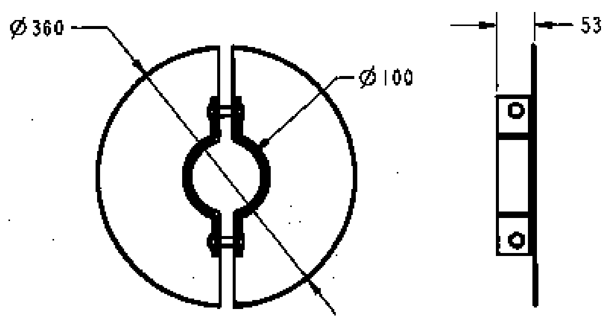

Fig. 3 : Schematic view of disc blade

Plate 1 : Compression reel ahead of rotor assembly with extended frame

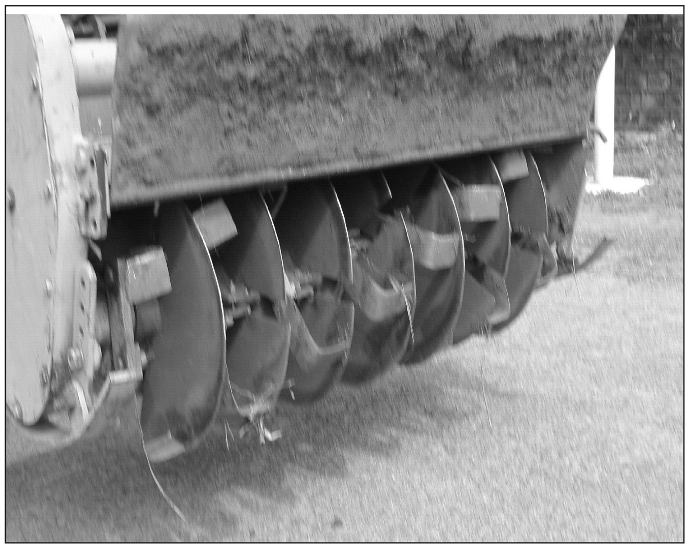

Plate 2 : Modified L -blade along with discs

Performance of rotary tiller

The performance of rotary tiller was assessed in terms of (i) biomass incorporation efficiency and (ii) chopping efficiency. To assess the incorporation efficiency, the amount of biomass placed on the surface was quantified in each plot before incorporation i.e., before running the machine. After incorporation, biomass remained on the surface was collected by hand. Three replications were taken to calculate mean values. Biomass incorporation efficiency (η_i) in percentage was calculated as below:

$$\eta_i = [(W_a - W_b) / W_a] * 100 \qquad (1)$$

Where,

W_a = Weight of biomass on surface before incorporation, g

W_b = Weight of biomass left on the surface after incorporation, g

To assess the chopping efficiency, the amount of biomass placed on the surface was quantified in each plot before incorporation i.e., before running the machine. After incorporation, sub samples of biomass having chopped length less than 8 cm were collected randomly from 1 m^2 area at depth of 15 cm, cleaned if any adhered soil using brush and weighed. Metal template of size 50 x 50 x 5 cm was used for sampling. Samples were collected from every first 5 cm depth till total depth of 15 cm and cumulated. Three samples were taken and the data were averaged to get the mean value. The chopping efficiency in percentage was calculated with equation given below:

$$\eta_c = (W_d/W_c) * 100 \qquad (2)$$

Where,

W_c = Weight of biomass before incorporation (excluding leaves), g

W_d = Weight of chopped material below 8 cm length, g (size was considered to be maximum limit to avoid clogging during subsequent operation with tyne cultivator).

The performance of newly developed rotary tiller was assessed in terms of incorporation efficiency and chopping efficiency and compared with existing model. Test crops were three, *viz.* (i) cowpea (ii) horsegram and, (iii) sunhemp. The effect of soil moisture on performance of newly developed rotary tiller was ascertained by taking five levels of soil moisture *viz.,* 6, 12, 18, 24, and 30% at Hayatnagar Research Farm, CRIDA Hyderabad. It was also tested in two soil type's *viz.*, (i) Alfisols at Hayatnagar Research Farm, CRIDA, Hyderabad and (ii) Vertisols at Thimareddyguda of Shahbad Mandal, Rangareddy district, Telangana. In both the soil types, rotary tillers were operated at similar depth (15 cm) of tillage.

Results and Discussion

Incorporation efficiency

Biomass incorporation efficiency of existing and modified rotary tiller is presented in Figure 4. It is observed that incorporation efficiency of modified rotary tiller was considerably higher than that of existing rotary tiller in case of three test crops under study. Evidently, incorporation efficiency of modified rotary tiller in case of cowpea, horsegram and sunhemp crops was 80, 86 and 72% than that of existing rotary tiller (54, 60 and 44%, respectively). The variation in incorporation efficiency among the crops was attributed due to variation in crop stem properties, crop geometry and crop height.

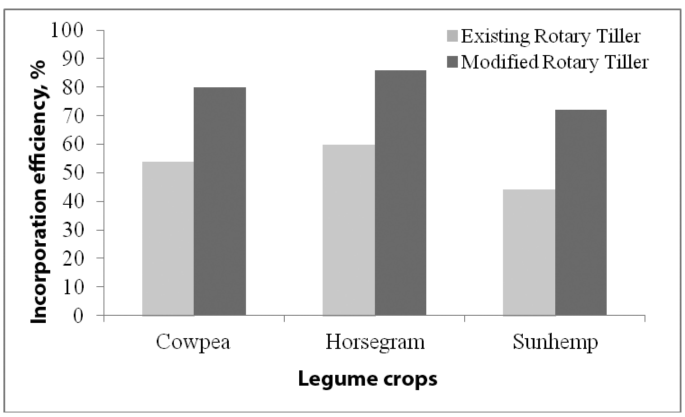

Fig. 4 : Incorporation efficiency of existing and modified rotary tiller for in-situ incorporation of legume crops

Chopping efficiency

Chopping efficiency of both the existing and modified rotary tillers for *in-situ* incorporation of legume crops is presented in Figure 5. It is seen that chopping efficiency of the modified rotary tiller in case of all the three test crops was substantially higher as compared to the existing rotary tiller. Obviously, chopping efficiency of modified rotary tiller in case of cowpea, horsegram and sunhemp was substantially higher at 81, 78 and 69%, as compared to the existing rotary tiller (38, 32 and 21%, respectively).

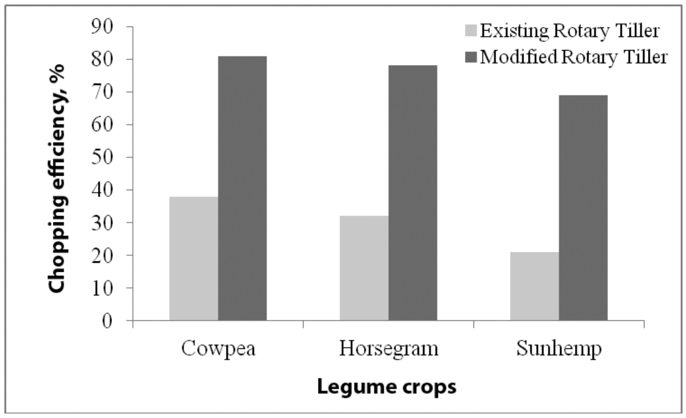

Fig. 5 : Chopping efficiency of existing and modified rotary tiller for in-situ incorporation of legume crops

While working with machine, it was observed that modified blades cut the soil slice more effectively and scoop the soil to a greater extent along the lateral plane till the blade knocked off the cutting trajectory. This resulted to increased amount of soil stir leading to increased quantities of biomass incorporation. The compression reel rotating ahead of main rotor assembly facilitated the grip of crop-stem and arrested the entanglement of twigs to the rotor and hence increased the performance. Compressing the biomass ahead of rotary tiller with compression reel increased interaction between blade and biomass and ultimately resulted in increased incorporation and chopping efficiency. During operation, it was noticed that entangling of the twigs and stems with modified rotor assembly was very less as compared to the existing rotor.

Effect of soil moisture on incorporation efficiency

The incorporation efficiency of existing and modified rotary tillers was assessed at five levels of soil moisture *viz.*, 6, 12, 18, 24, and 30% for cowpea incorporation. Incorporation efficiency of modified and existing rotary tiller each as dependent on soil moisture level at the time of incorporation is depicted in Figure 6. The relationship is best fitted with polynomial curve with r^2 value of 0.9187 and 0.8678 in case of modified as well as existing rotary tiller, respectively. Incorporation efficiency of modified rotary tiller established direct relationship with soil moisture levels. It showed that the incorporation efficiency increased from 24 to 88% with the increase of soil moisture level from 6 to 18%. Then onwards, further increase in soil moisture level reduced the incorporation efficiency. Similar situation was observed with existing rotary tiller. It is also seen that penetration of blades into soil was poor when soil moisture was 6% which resulted in lower incorporation efficiency. With soil moisture exceeding 18%, incorporation efficiency reduced mainly because of clogging of soil in rotor assembly. On an overall, 18% soil moisture level was found to be optimum for attaining maximum biomass incorporation with rotary tillers.

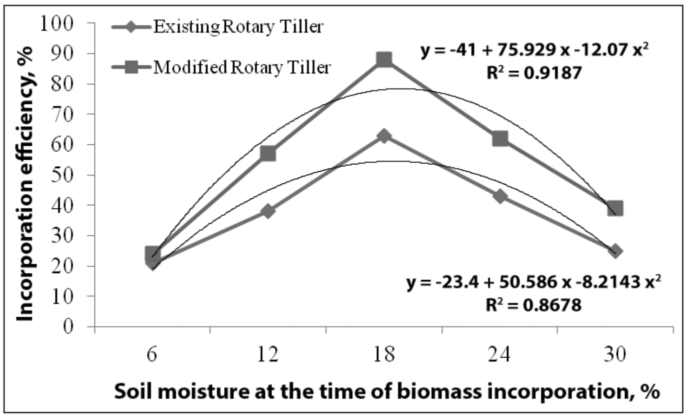

Fig. 6 : Incorporation efficiency of existing and modified rotary tillers at various soil moisture levels at the time of incorporation

Variation in biomass incorporation versus soil type

Performance of both existing and modified rotary tillers in Alfisols and Vertisols soil types is given in Figure 7. It showed that incorporation efficiency of both rotary tillers varied with soil type. Both rotary tillers performed better with higher incorporation efficiency in Alfisols than that of Vertisols at 15 cm depth of operation. Since, Vertisosl contain more clay than in Alfisols, the cohesiveness of clay caused often clogging of blade chord leading to reduction in the incorporation efficiency of rotary tiller.

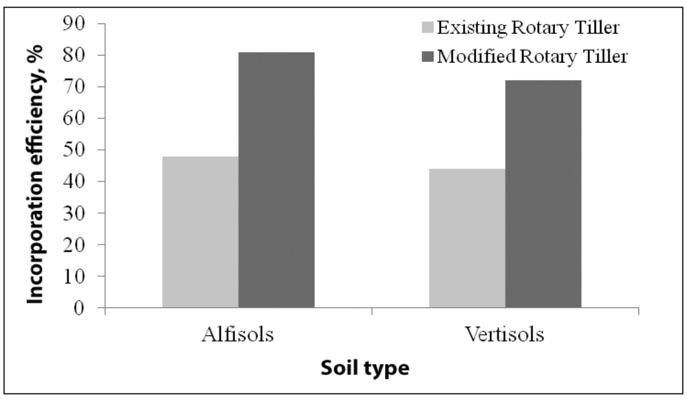

Fig. 7 : Incorporation efficiency of existing and modified rotary tillers for different soil types

Conclusion

Biomass incorporation though beneficial, is not widely adopted due to non- availability of suitable machines. Existing rotary tillers are more suited to residue incorporation, rather than incorporating cover crops/legumes like sunhemp, cowpea, and horsegram. With new interventions of critical component, it could be feasible to increase the performance of rotary tiller for *in-situ* biomass incorporation. The optimum level of soil moisture for better performance of rotary tiller was identified as 18% to achieve higher biomass incorporation efficiency, this may be recommended for higher adoptability of modified rotary tiller in Alfisols.

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