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Harvesting and Threshing Methods for Paddy-I: A Review

Shekhar Kumar Sahu[1,2]

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ABSTRACT

Harvesting methods adopted for paddy crop are largely dependent on the land size of the farmers. Mechanized methods are completely implemented by the farmers of medium and large categories. On the other hand, the marginal and small farmers are struggling between manual and mechanized methods because of unavailability of implements that can suit to their land size an economic level. Cutting and threshing operations are performed separately which are responsible for more input cost and grain loss. Various methods of harvesting were studied and the loss of grain associated with the methods is emphasized. In manual method, before threshing, the cutting, collecting, bundling and transportation operation requires which consumes time, energy and cost and increase the grain loss significantly. In mechanized methods, the time, energy and input cost can be minimized. The manual crop cutting requires about 8 to 12 and 25 to 45 times, respectively, more man-hours per hectare compared to rotary blade cutter and vertical conveyor reaper. The field capacity of manual harvesting methods is 4 to 10 times less than the mechanized methods.

Key words: Conventional header, Harvesting, Header loss, Reel index, Stripping.

Rice, (*Oryza sativa*) is a staple cereal food consumed by a large population in India. In the past several years, Indian farmers have been facing a challenge of producing enough food for a very large and rapidly growing population while the labour engagement in the farm has been declining. In the year 2004-05, the agricultural workforce was 258.93 million which decreased to 228.36 million in the year 2011-12 (Singh and Kapoor, 2015). To increase production with a decrease in the agricultural workforce, it has become essential to mechanize the farm operations to save time and reduce dependency on human labour. This will also help in maintaining the timeliness of agricultural operations. As per the statistics of Food and Agriculture Organization (FAO) of the United Nations, the production and productivity of rice in India were 169 million tons and 3.87 ton ha^{-1}, respectively in the year 2017 (Anonymous, 2020a). This puts India to the second position in the world in the production of rice after China. As per the land use statistics of 2016-17, the total geographical area of India was 328.7 million hectares and the net sown area was 156.4 million hectares. Out of this, 43.79 million hectare land, that is, approximately 28% of the total sown area was under cultivation of rice. It contributes significantly to the economy of India. According to the FAO report, rice was grown globally over an area of 167.13 million hectare land in the year 2018 from which the production was 782 million ton (Anonymous, 2020b). Asia had the largest share of 90.7% in production. On the other hand, the share of America, Africa, Europe and Oceania was 5.2, 3.4, 0.6 and 0.1%, respectively. The average production of top ten rice-producing countries of the world in the 25 years from 1994 to 2018 is shown in Fig 1.

To feed the huge population, it is necessary to reduce the losses that occurred during the various farm operations. In different studies, it was reported that harvesting and threshing are major operations that are responsible for grain loss. It may reach more than 8% only in harvesting and threshing operations. In this study, different methods adopted for harvesting of paddy crop and the grain loss occurred during harvesting is discussed.

[1]Department of Agricultural Engineering, School of Agriculture and Bio-Engineering, Centurion University of Technology and Management Paralakhemundi, Gajapati-761 211, Odisha, India.
[2]Department of Agricultural Engineering, Horticulture College, Khuntpani Chaibasa, Birsa Agricultural University, Kanke Ranchi-834 006, Jharkhand, India.

Corresponding Author: Shekhar Kumar Sahu, Department of Agricultural Engineering, School of Agriculture and Bio-Engineering, Centurion University of Technology and Management Paralakhemundi, Gajapati-761 211, Odisha, India.
Email: shekharsahu6789@gmail.com

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Harvesting of paddy crop

Separation of main or economic product in a crop is known as harvesting (Srivastava *et al.*, 2006; Anonymous, 2019a). Cutting, picking, plucking, digging or a combination of these operations comes under harvesting (Anonymous, 2019b). Selection of the harvesting method depends on the type of crop. Cutting of the crop is the first operation (Srivastava *et al.,* 2006). In shear cutting the plant is supported by one hand in manual methods or on a counter blade in mechanical methods and a cutting blade applies the force on the stems. The inertia of plant and the stiffness of the stem provides strength against the application of force during impact cutting. In rice cultivation, harvesting is a very important operation. It involves cutting of the plants, bundling them, transportation of the bundles and threshing. In India, these field operations are carried out either manually or using small equipment at different stages.

Separating of individual panicles of paddy crop with the hands, gathering them and then cutting them with a knife required an average of 240 man-hours ha^{-1} (Khan, 1971). Cutting of paddy crop using sickle consumed an average of 80 to 160 man-hours ha^{-1}. International Rice Research Institute estimated that the manual cutting cum gathering operation and threshing operation required 200 and 120 man-hours ha^{-1}, respectively (Anonymous, 2013). Singh (2016) evaluated the work capacity and physiological workload of women during manual cutting of paddy crop variety Kanti. Three types of sickle *viz*. Naveen, Vaibhav and an improved local design were used. It was reported that average cutting capacity of a woman when using these sickles was 0.0047, 0.0061 and 0.0065 ha h^{-1} and consumed physiological energy 0.61, 0.52 and 0.47 kW ha^{-1}, respectively. Harvesting one hectare of paddy crop manually required 213, 164 and 154 man-hours, respectively. Blade design affected labour requirement. Bora and Hansen (2007) assessed the performance of a rotary blade cutter in cutting paddy crop. It was equipped with circular disc of 25 cm diameter and powered by a gasoline engine. Average cutting capacity and fuel consumption were reported to be 0.064 ha h^{-1} and 0.25 l h^{-1}. In comparison with sickle harvesting, it consumed 7.8 times less time. Murumkar *et al.* (2014) evaluated the performance of a self-propelled vertical conveyor reaper (VCR) in paddy crop. They operated a model "VCR KAMCO KR 120" which had 1.20 m working width and was fitted with a 2.6 kW engine. At an average forward speed of 3 km h^{-1}, actual field capacity and fuel consumption of machine were 0.28 ha h^{-1} and 0.8 l h^{-1}, respectively. It cut the crop and laid them on the ground. Collection and bundling of the cut crop were carried out manually. Total labour required for reaper operation, manual collection and bundling were 88 man-hours per hectare. Out of this, only 3.6 man-hours per hectare (4.10%) were used in reaper operation.

There is a shortage of labour at the peak season leading to delay in the operation. Delay in cutting the crop and delay in threshing after cutting lead to grain loss (Selvi *et al.,* 2002). Selvi *et al.* (2002), reported that 1, 2, 3 and 4 weeks of delay increases the grain loss by 5.63, 8.64, 40.70 and 60.46%, respectively. Prabakar *et al.* (2011), reported that labour scarcity and technology deficiency can cause a reduction in productivity of rice crop up to 11.80 and 12.60%, respectively. According to them, Indian farmers are not very adaptive towards new technologies due to the high initial cost. Combine harvester can reduce dependence on labour. It accomplishes all operations- cutting, threshing, separating and cleaning at a timein a single pass. It starts the operation with the header. It guide, cut and gather the plants and transport them to the threshing cylinder (Anonymous., 1994). In a crop cutting machine, components are provided to guide the crop plants. These are used to perform proper collection, holding and windrowing of the crop, respectively, before, during and after cutting operations. In rotary blade cutter, a semi-cylindrical sheet is provided. In vertical conveyor reaper, the crop divider, star-wheel and lugged flat belts are provided for this purpose. The spread plants are required to be guided before feeding to the cutting and stripping units of header. In standard and stripper header combines, reel and guiding hood are provided for this purpose.

Conventional grain header

The components of a grain header are reel, cutter bar, platform and conveyor (Fig 2). The reel is equipped for gathering and guiding the plants. It bend the plants at the top, holds them for cutting and push them towards the platform after cutting. The reel lifts the lodged plants (Miu, 2015). The reel has several bars that are perpendicular to the direction of travel. These bars are arranged on a circle around a shaft and rotate along the circle. The bars are interconnected through rings of polygonal or circular shape.

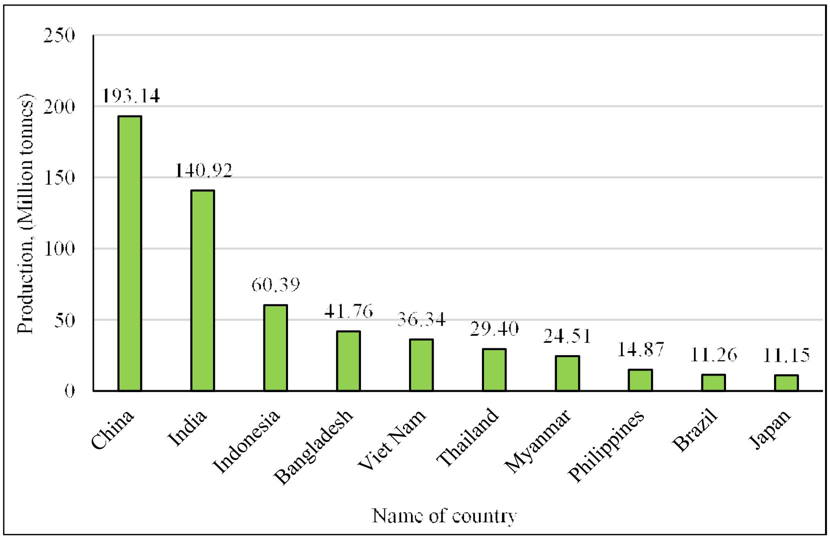

Fig 1: Average paddy production of top ten producer countries of 25 years from 1994 to 2018 (Anonymous, 2020b).

The rings are connected to shaft through spokes. The bars carry spikes that maintain proper inclination when rotates. They gather and hold the plants. The shaft of reel is mounted horizontally and is located above and ahead of the cutter bar. The height and forward distance of the shaft from the cutter bar shall be adjusted according to the height of the plants to be harvested. The header has a cutter bar that cut the plants at height h_{ct} (Fig 2) and the plants fall over the platform. A conveyor conveys the cut plants towards the middle from both sides of the platform. Another conveyor provided at the middle of the platform delivers the plants to the threshing cylinder (Kepner *et al.,* 2005).

Effect of reel index on operation

The reel index is a kinematic parameter and is defined as the ratio of peripheral speed of reel tip to the forward speed of machine. This ratio decides the shape of path of the spike which affects posture of the plant and its falling tendency (Miu, 2015).

$$\lambda_r = \frac{R_r \times \omega_r}{V_c} \qquad \text{....(1)}$$

Where

λ_r, R_r, ω_r and V_c are the kinematic reel index, reel radius, angular velocity of reel and forward velocity of harvester, respectively. If $\lambda_r < 1$, then the reel bar does not bend the crop towards the cutter bar, adversely, it moves the crop farther to the front side of the machine and no part of the crop will be collected. If, $\lambda_r = 1$, then the reel does not influence the crop movement, but its striking spikes may cause shattering of grain and if $\lambda_r > 1$, this is a condition for the reel to serve its purpose. This condition allows the uncut crop to bend towards the header platform.

Pick-up reel header

The pick-up header combine is used for picking up the crop which is previously cut and windrowed in the field (Srivastava *et al.,* 2006). It has a wide conveyor belt equipped with equidistant tines. The belt rotates on the roller in a direction perpendicular to the direction of machine travel. When the machine moves forward, the tines of the belt penetrates into the stubble and lift the swath on to the belt. The front end of the header is supported on two wheels that help to maintain the clearance against the undulated ground and ensure proper picking of the crop. The picked crop is moved towards the auger from where it is delivered to the threshing unit through another conveyor. The speeds of picking belt and feeding auger are synchronized with the forward speed of the machine. These can be varied according to the moisture content and straw length.

Stripper header

A stripper header introduced by Keith Shelbourne (Anonymous, 2019c) in the mid of 1980s.and first model was launched in the market in the United Kingdom in 1989 (Anonymous, 2019c). Within a few years till 1996, it had been exported from the United Kingdom to more than 30 countries (Tado *et al*., 1998). It was used to harvest up to 25% of the total paddy crop in United States, Australia and South America (Miu, 2015). The reason behind its acceptance was its higher throughput capacity at 61.2 tons h^{-1} and higher operating speed at 2.2 to 5 m s^{-1} (Kutzbach and Quick, 1999). The grain loss remained within acceptable limits. It consumed less amount of fuel compared to the standard and pick-up reel-type headers. The modifications on header were made regularly as per the need of the farmers (Peries, 1990 and Anonymous., 2018a).

In the very initial design, the stripper rotor first delivers the stripped ear heads to the draper belts which feed the material to the auger. Due to concerns regarding the life of draper belts, it was discontinued. In the next model, the conveyor belt was replaced by a steel shaker pan which enhanced the convenience in the feeding of wet and heavy panicles from the stripping rotor to the auger. To improve

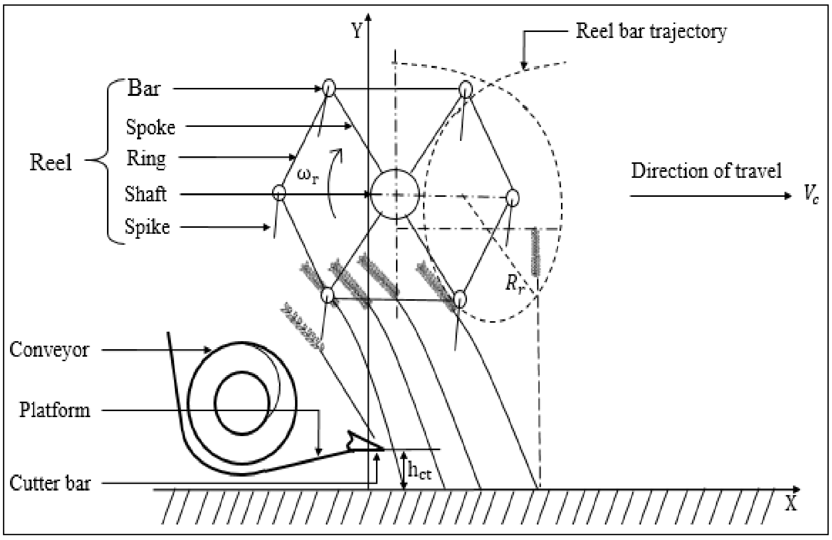

Fig 2: Schematic side view of the grain header during operation.

the durability of the header, its components were made of hardened stainless steel. Later its production was stopped because it was not able to feed the crop directly to the auger conveyor. In all the previous models, the auger and rotor are kept close to each other so that the grains could be delivered directly to the auger. Later auger platform was modified by making it deeper. It was evaluated extensively on the field conditions. Thereafter, it was found that it served better in feeding than the flat one.

The stripper header consists of a hood, stripper rotor and two conveyors (Rahman, 2007). In comparison with a conventional grain header which feeds the whole plants into the threshing cylinder, it strips off the panicles only. It does not cut the plants. Schematic diagram of the stripper header is shown in Fig 3. The hood (1) deflects the upper part of the plants in the forward direction through a guide nose (2). The ear heads then reach the stripper rotor (3). The stripper rotor rotates about a horizontal axis perpendicular to the direction of travel of the machine. It carries a set of fingers (4) on its periphery. Slots are provided on the stripping fingers. This is shown in an expanded view in Fig 3. The ear heads (5) are stripped from the plants by the combing action of the fingers and thrown to a platform (6). The auger conveyor (7) convey the stripped material. These are then picked by another conveyor and delivered to the cylinder.The stem portion of plant remains in field in a standing posture.

Chowdhury (1977) proposed the design of stripper harvester that can be operated using power tiller and thresh only the ear heads in the field itself. A technique of a differential impact action of the stripping spikes was suggested. The crop row was passed through the gap between units composed of two shafts mounted parallel at a distance. The shafts were equipped with stripping fingers and rotates about vertical axis for stripping the ear heads. This design was proposed for the crop that remains in standing posture and had limitations for the lodged crop.

The main purpose of stripper header combine is to strip only the panicles from the plants for reducing the high feed rate. Before it was tried, the cutter bar of some conventional harvesters was raised and tried. The throughput capacity increased with a decrease in energy consumption. Klinner *et al.* (1987) justified the increase in height of the cutter bar. They operated the conventional harvester keeping the cutter bar as high as possible and found that the grain throughput capacity could be increased by 50 to more than 100%. It indicated that the work rate of the harvester depended on straw throughput rate. The conventional header could be replaced by a stripper header. Also, the ear heads could be transported after stripping for threshing at a different location. These reduce the straw intake and energy consumption per unit grain throughput considerably. The Silsoe Research Institute, UK developed a stripper harvester and evaluated its performance. They reported that the stripper header increased the capacity of the harvester by 50-100% while power consumption decreased (Miu, 2015). Progressively the concept of stripper grain harvester came into existence.

Effect of stripper index on operation

The stripper index is given by an expression given in Eq. 2 (Yuan and Lan, 2007 and Miu, 2015).

$$\lambda_s = \frac{R_s \times \omega_s}{V_c} \qquad \text{....(2)}$$

Where,

λ_s, R_s, ω_s and V_c are the stripper index, radius of the stripper rotor, angular velocity of the stripper rotor and forward velocity of combine harvester, respectively. The stripper index value influences the grain loss by stripper rotor if λ_s d≤1, the rotor does not strip the ear heads of the plant but deflects them in the forward direction and if λ_s>1, this is the condition at which stripper finger of the rotor strips the panicles.

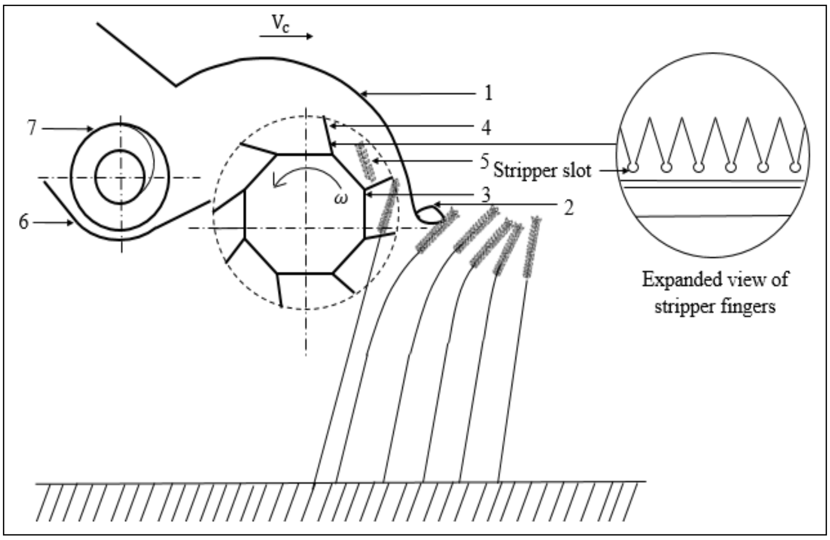

Fig 3: Conceptual diagram of the stripper header.

Losses associated with header

To achieve higher throughput capacity, there is a need to operate the combine at a higher forward speed with low straw intake. The straw intake can be minimized by increasing the cutter bar height which depends on the crop variety. According to different researchers, the height of paddy plants ranges from 47 to 182 cm for different varieties. The speeds of reel and cutter bar are synchronized with the forward speed. When forward speed increases, speed of reel and cutter bar was also increased. An increase in reel speed increases grain loss due to shattering. This was found in an experiment carried out by Goss *et al*. (1958) and Wilkinson and Braumbeck (1977) during harvesting of barley crop. They varied reel index and determined the grain loss. The X value in (X, Y) notation shown in Fig 4 represents the horizontal distance in centimeter of the spike tip at its lowest position from cutter bar tip. The Y value represents vertical distance of tip at the same position. Goss *et al.* (1958) operated a combine harvester in an upright crop with fixed bat reel which was 24 cm ahead and 15 cm above the knife bar. They observed that the variation in reel index from 1.25 to 2.80 resulted in an increase in loss from 3 to 6%. When operated with fixed bat reel and with pick-up reel in upright and in lodged crop conditions the reel index varied from 1.25 to 2.80 at various reel locations also shown in Fig 4. It was reported in their study that the grain loss increased from 4 to 8% and 3.2 to 8%, respectively in fixed bat and pick-up reel when the reel index increased from 1.25 to 2.80 for the upright crop. In the case of the lodged crop, the grain loss increased from 0.6 to 4% and 1.4 to 2% in fixed bat and pickup reel, respectively. This shows that the cutter bar loss was least at the reel index value of 1.25 for lodged and upright crop.

The conventional and stripper headers are capable of harvesting the moist crop which reduces the possibilities of grain loss due to shattering (Anonymous, 2013). The load on the threshing system can be reduced by reducing the straw intake by raising the cutter bar in the conventional header while in the case of stripper rotor the load is minimized by feeding only the panicles (Yuan and Lan, 2007 and Chegini, 2013). In case of undulated fields, the reel and cutter bar need to be raised to reduce damage of the knife, while in case of stripper header, the field undulation does not affect the header. The pickup reel header works effectively in case of lodged or windrowed crop conditions (Srivastava *et al.,* 2006). The grain loss occurs due to shattering when the rotating reel strikes the ear heads of the crop. Moreover, the vibratory action of the cutter bar may also cause shattering loss (Hunt, 2008). Above this range, the cutter bar requires more power to cut the plants and more load is experienced by the threshing cylinder (Miu, 2015). It consists of many moving components which include reel (or stripper rotor), cutter bar, auger and conveyor. These components consume a significant amount of power to deliver the crop into thresher (Kalsirisilp and Singh, 2001). The standard reel header and stripper header are less efficient for harvesting of lodged crop compared to the pick-up reel header. In the standard header, the shattering of grain occurs during lifting of the lodged crop by the reel (Hunt, 2008), whereas, in a stripper header the grain loss increases due to poor stripping of the panicles. The straw portion of the crop is left in the field in standing condition after stripping of the panicles. However, in the standard and pickup reel header the straw portion is cut and collected (Kalsirisilp and Singh, 2001).

The cost of operation and labour requirement for different harvesting methods were estimated on the basis

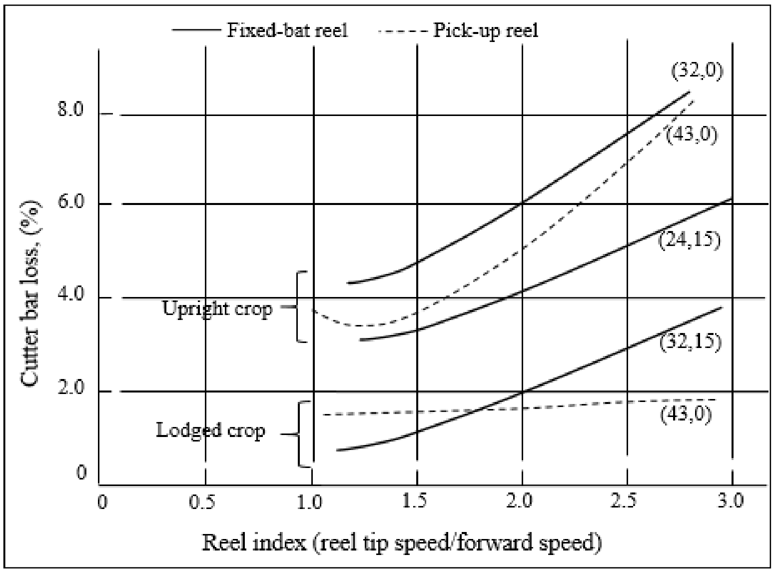

Fig 4: Losses associated with reel adjustment in reel header combine harvester (Wilkinson and Braumbeck, 1977).

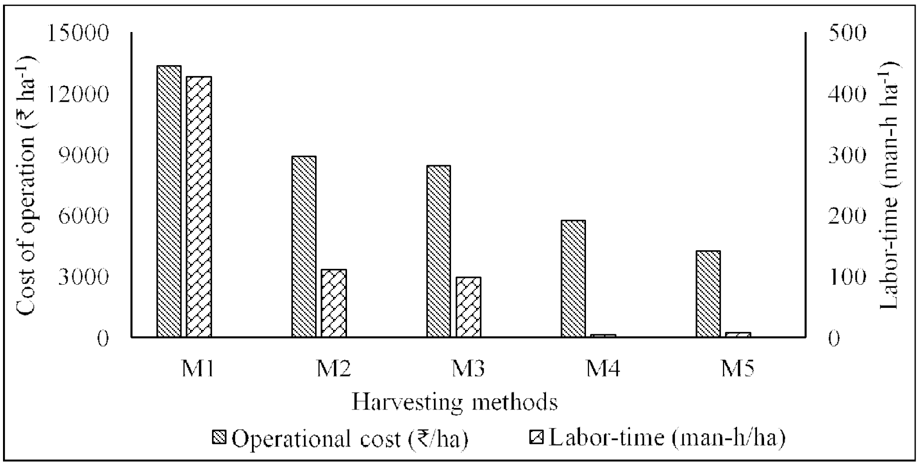

Fig 5: Cost of operation and labour-time requirement of different methods of paddy harvesting.
M1= Manual cutting, gathering, hand beating threshing and grain cleaning, M2= Rotary blade cutter, manual gathering, threshing using power thresher, M3= VCR, manual gathering and threshing using power thresher. M4= Harvesting with conventional header combine. M5= Harvesting with stripper header combine.

of data available and graphically represented in Fig 5. It is shown that manual harvesting and threshing consume maximum input cost and labour among all methods of harvesting and threshing. By using rotary blade cutter and VCR the input cost can be saved upto ` 5000 per hectare when compared with manual harvesting and threshing. On the other hand, using reel and stripper combine harvesters, the input cost can be saved by ` 7000 and 9000 per hectare, respectively, in caparison to manual harvesting.

SUMMARY AND CONCLUSION

The manual crop cutting requires about 8 to 12 and 25 to 45 times, respectively, more man-hour per hectare compared to rotary blade cutter and vertical conveyor reaper. It is more time-consuming and costlier than mechanized methods. In harvesters, crop guides are provided for directing the crop before or during the cutting and stripping operation. The height of guiding units *i.e.* reel and guiding nose depends on the height of the plants. According to different researchers, the height of paddy plants ranges from 47 to 182 cm for different varieties. Grains are distributed along the height of the plant starting from a minimum height and up to the tip of the plant. The field capacity of manual harvesting methods is 4 to 10 times less than the mechanized methods. The grain throughput rate of conventional combine harvester can be increased by reducing the straw intake by increasing the cutter bar height.

Conflict of interset: None.

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