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Nisha
Teaching Assistant, Department of Farm Machinery and Power Engineering, TNAU, Coimbatore, Tamil Nadu, India

Saravanakumar
Associate Professor, Farm Machinery, Department of Farm Machinery & Power Engineering, Agricultural Engineering College & Research Institute, Kumulur, Trichy, Tamil Nadu, India

Shridar
Dean, Agricultural Engineering, Agricultural Engineering College & Research Institute, TNAU, Coimbatore, Tamil Nadu, India

Corresponding Author
Nisha
Teaching Assistant, Department of Farm Machinery and Power Engineering, TNAU, Coimbatore, Tamil Nadu, India

Development and evaluation of tractor front mounted finger millet harvester

Nisha, Saravanakumar and Shridar

Abstract
A tractor front mounted finger millet harvester was developed for harvesting finger millet earheads and stalks seperately. The components of developed finger millet harvester includes harvesting unit, conveying and collection unit for earheads and windrowing unit for stalks. The harvesting unit consists of two cutter bar assembly of length 1600 mm and a reel. The collection and conveying unit for earheads consists of a screw conveyor for conveying harvested earheads and a collection bin for collecting it. The power for the harvester was taken from tractor PTO with 540±10 rpm to the front of the tractor using belt pulley, main shaft and a universal joint. The machine worked satisfactorily during field performance evaluation in sandy loam soil. The maximum harvesting efficiency achieved was 91.5 per cent with 1.25 percent header loss.

Keywords: Fodder, labour intensive, reel, screw conveyor, collection bin

1. Introduction

Finger millet is cultivated in more than 25 countries in Africa and Asia. Uganda, India, Nepal, and China are the major finger millet producers of world. In India, it is extensively grown in Karnataka, Tamil Nadu, Andhra Pradesh, Orissa, Bihar, Gujarat, Maharashtra, the hilly regions of Uttar Pradesh and Himachal Pradesh. Karnataka is the leading producer of finger millet with 53.94 per cent of the total area and 53.36 per cent of the total production of finger millet crop in the country. Tamil Nadu occupies second place in respect of area (7.52 per cent) and production (14.60 per cent) of finger millet in India. The chief producers of finger millet are Coimbatore, Dharmapuri, Ramanathapuram, Salem, North and South Arcot, Nilgiris, Chengalpet and Madurai districts. The area under finger millet has declined from 2.6 million ha in early sixties to around 1.06 million hectare in 2016-17.

Manual harvesting of finger millet (whole crop) using sickle involves 25 man days per hectare. Scarcity of labor and higher wages during harvesting season is a serious problem, which increases the cost of production. Similarly, lack of appropriate machinery is one of the barrier for increasing the production and productivity of finger millet crop. To harvest finger millet, small scale farmers uses hand tools, such as scythe or sickle or they use combine harvester which again requires labour for separating the earhead from the stalk (Pitzer, 2010). Harvesting using combine harvester is cumbersome and harvesting using hand tools is time consuming and labour intensive. Both the techniques are not suitable for small scale-grain production. Hence an appropriately scaled machinery is needed for harvesting finger millet cultivated by small scale farmers. Earlier researches undergone for harvesting finger millet is discussed below.

Kumar and Chowde Gowda (2005) modified a self-propelled paddy reaper for harvesting finger millet. They modified the paddy reaper by replacing belt power transmission system with a combination of universal joints and incorporating stronger pressure springs, sturdy frame and crop dividers which was mounted with 15 hp power tiller. The overall performance of the modified reaper for finger millet harvesting was reported to be satisfactory. They concluded that the modified unit achieved 96 per cent efficiency, 55 per cent saving of time and 60 per cent saving of operational cost as compared to manual harvesting with sickle.

Balappa *et al.* (2012) developed a working prototype for ragi harvesting and threshing. The developed unit consists of a double knife cutter bar, a vacuum roller assembly for guiding the plants to the conveyor and a threshing system.

Suning *et al.*, (2015) [5] designed and developed a millet combine harvester. The harvester consisted of a header, reel, conveyor, threshing system and cleaning system. The field experiment and performance test results showed that the developed harvesting machine has achieved a stable performance. They have concluded that the developed harvester saved operation time by over 90 per cent while reducing labor intensity, promoting efficiency and cutting cost compared to manual harvesting.

Ali and Kamalabai (2017) [3] studied about the role of mechanization in effective management of time and labour in ragi cultivation using a paddy reaper. They have reported that mechanization reduced the time of operation by 76 per cent comparing to conventional harvesting. They have also reported that harvesting of ragi using reaper left much of stubble in the field which resulted in low fodder availability.

Syed Mazaril (2017) evaluated the performance of mechanical reaper for ragi harvesting. Their results showed that harvesting of ragi using reaper reduced the time of operation by 72 per cent, total labour dependency by 92 per cent and cost of cultivation by 81 per cent as compared to manual operation. The field capacity of reaper was found to be 0.23 hah^{-1}.

Currently there is no commercialized harvester particularly for finger millet crop. The modified harvesters available cut only the whole crop. Harvesting of whole crop limits the usage of the crop as fodder since separating fodder from the harvested crop needs additional labour, which increases the cost of production. There is, thus a need for developing a finger miller harvester for harvesting the earheads and stalk separately. The objective of the present study was to develop a working prototype harvester for finger millet and to optimize the machine and operational parameters under field conditions.

2. Materials and Methods

A tractor front mounted harvester was designed to cut the earhead first, convey and collect the earhead in the collection bin and secondly to cut the stalks and convey and windrow it in field. The finger millet harvester consists of two cutting units: one for cutting the stalks and other for cutting the earhead, a reel for pushing the earhead to be harvested towards the cutter bar, a screw conveyor for conveying the harvested earheads, a star wheel and flat belt conveyor for windrowing the finger millet stalk, power transmission assembly. The Finger millet harvester developed is shown in Figure 1.

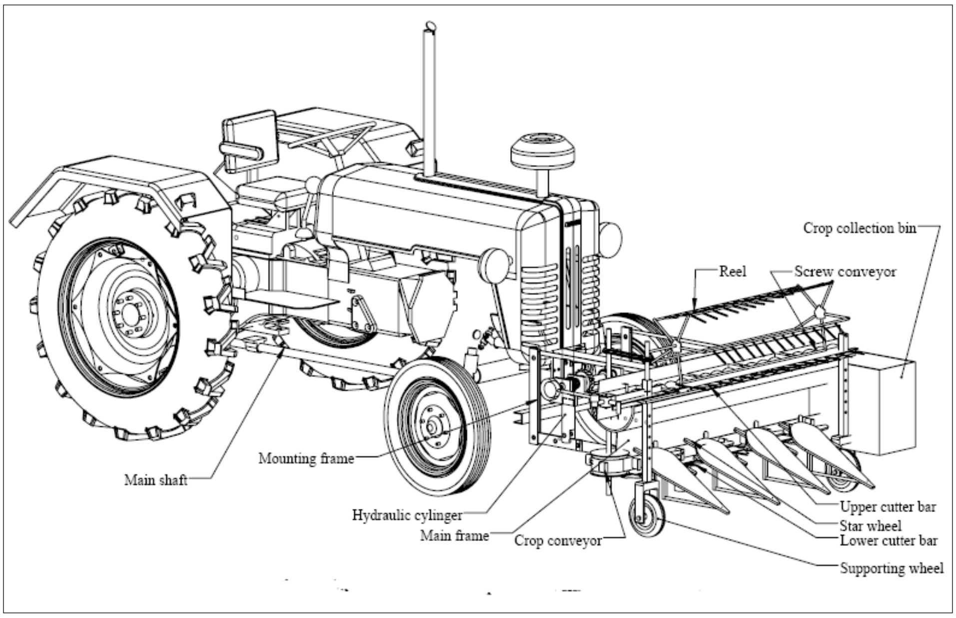


Fig 1: Tractor front mounted finger millet harvester

2.1 Cutting units

The harvesting unit comprises of two cutter bar assembly: one upper and one lower cutting unit. Both the cutting units were mounted on a rectangular main frame of overall dimension 1650 × 150 × 500 mm made of mild steel "L" angle of size 25 × 25 × 6 mm. The cutter bar assembly consists of a cutter bar knife, knife guard and knife clip.

2.1.1 Upper cutting unit (A)

The height of the upper cutting unit from ground level was selected as 460 mm. The upper cutter unit was mounted at a horizontal off set distance of 200 mm in front of the lower cutting unit. So that the earhead were cut ahead of the stalk with certain time interval. The total width of the upper cutting unit was 1600 mm.

2.1.2 Lower cutting unit (B)

The height of cut of the lower cutting unit was set at 100 mm above the ground level to avoid obstacles on the ground surface. A slider crank four bar mechanism was used to convert the rotary motion into reciprocating motion. The total width of the lower cutting unit was 1600 mm.

2.2 Reel system

The function of the reel system is to feed the crop to the upper cutting unit of the harvester and to lift the lodged crops for harvesting. For lodged crops, pickup tine reel provides better control over plants when compared to bat reel (Quick and Buchele, 1974). Hence a tined pickup reel was selected for the study. Rotational speed of reel and its mounting height plays a vital role in harvesting.

A reel of total length 1580 mm was mounted on the top of main frame using two hollow reel mounting tubes of length 890 mm and diameter of 20 mm fitted on both ends of the frame of upper cutting unit. The six reel tine bars were fabricated using hollow tube of 1580 mm length and 20 mm outer diameter. The horizontal mounting distance and vertical mounting distance can be adjusted. The reel shaft on the left side of the reel was used for power transmission.

2.3 Conveying and collection system for earheads
The prototype finger millet harvester was provided with a screw conveyor to convey the harvested finger millet earheads to the left of the harvester and a collection bin for collecting the conveyed earhead.

2.3.1 Screw conveyor
A screw conveyor was located below the cutter bar assembly so that the cut earheads fall on the screw conveyor so that they are conveyed to the left end of the harvester. Based on the space availability the diameter of screw conveyor selected was 150 mm. The pitch of the screw conveyor plays an important role in conveying the harvested crop. The pitch (P) of the screw conveyor is equal to 0.8 to 1 of diameter of screw conveyor. The maximum rotational speed recommended for 150 mm screw conveyor diameter is 150 rpm (Design data, 2003). The screw conveyor clearance of screw conveyor was 16 mm for better conveyance for millets (Zareiforoush *et al.*, 2010).

2.3.2 Earhead collecting bin
A collecting bin was provided to collect the conveyed earheads. A collecting bin of 500 × 500 × 250 mm size was fabricated using mild steel 'L' angle of size 400 × 430 × 25 mm and covered with mild steel sheet of thickness 3 mm.

2.4 Conveying system for stalks
The conveying system for stalks comprises of a crop divider and star wheel for gathering the stalks to the lower cutting unit and a flat belt conveyor to convey and windrow the stalks. The maximum speed of flat belt conveyor varies from 1.6 to 1.8 ms^{-1} (Choudhuri, 1998). The speed of the flat belt conveyor is calculated using the following expression.

$$V_{con} = \frac{0.01 W_w V_m Q_y}{1.2\, h_t \rho} \quad (1)$$

Where, Ear speed of the belt conveyor, ms^{-1}
W_w = width of harvester = 1.7 m
V_m = forward speed of harvester = 0.833 ms^{-1} (assumed)
Q_y = yield of fresh finger millet stover = 28852 $kgha^{-1}$ (Wekha *et al.*, 2017)
h_t = height of throat of conveyor = 0.11 m
ρ = bulk density of crop = 2100 kgm^{-3}
The velocity of flat belt conveyor was calculated as 1.59 ms^{-1}.

2.5 Supporting wheel
A supporting wheel was attached on both sides of the harvesting unit to provide necessary support and for better balancing during operation. The supporting wheel of 200 mm diameter and 50 mm width was mounted on a central shaft of 19 mm diameter. The supporting wheel was provided with five holes at a center to centre distance of 50 mm for vertical adjustment of the supporting wheel. The supporting wheel moves into a hollow square tube of overall dimension 100 × 32 × 32 mm which was welded to the upper cutting unit mounting frame.

2.6 Power transmission unit
The power transmission unit plays a major role for transmitting power from the power outlet (PTO) of the tractor to the front mounted harvesting unit. The schematic diagram of the total power transmission system is depicted in Fig. 3. The power to the cutting unit was obtained from tractor PTO through gear box. The power to the upper cutting unit was obtained from the upper shaft. The power to the reel was obtained from the upper shaft which provides power to the upper cutting unit using a chain and sprocket assembly.

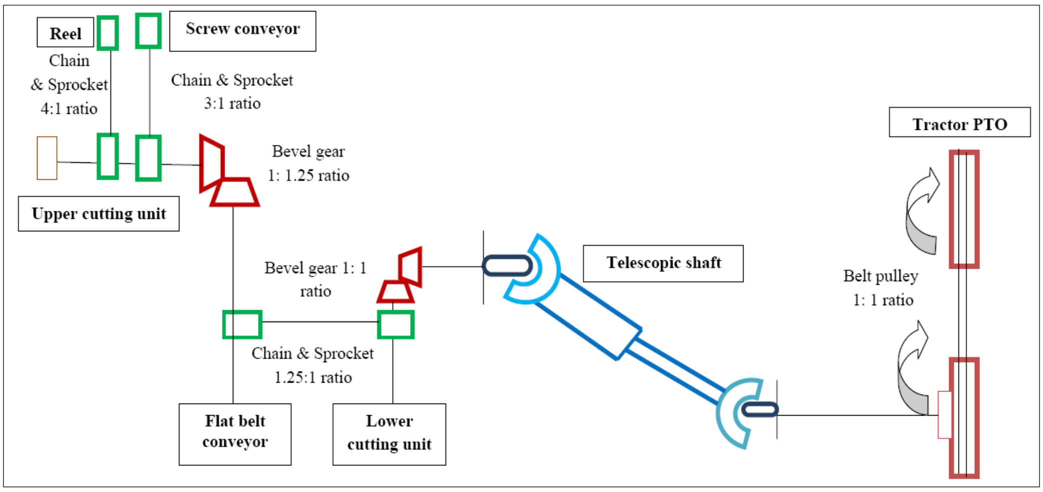


Fig 2: Power Transmission unit

3. Optimization of parameters
For field evaluation Co (Ra) 14 variety of finger millet is cultivated in Agricultural Engineering College and Research Institute, Kumulur. The crops at maturity stage was harvested using the finger millet harvester. The performance parameters are mentioned in Table. 1

Table 1: Performance parameters

S. No.	Parameters	Variables
1	Factors	Reel speed (N)
		Reel mounting height (M)
		Forward speed (S)
2	Affected response variable	Harvesting efficiency
		Header loss

3.1 Evaluation parameters
3.1.1 Harvesting efficiency
The harvesting efficiency was calculated by using the following expression

$$\eta_h = \frac{M_t - M_u}{M_t} \times 100 \qquad (2)$$

Where,
η_h= harvesting efficiency, per cent
M_t= total number of crops counted in 2.5 m^2 area
M_u= number of uncut crops counted in 2.5 m^2 area

3.1.2 Header losses
Before operating the finger millet harvester in field, natural losses (B) were measured. A metal frame of size 650 mm × 385 mm was used to determine the natural loss. The frame was placed at ten random places of field, then the dropped kernals and ears in the frame on the soil were gathered and counted at laboratory.
For measuring the header loss of finger millet harvester, at the end of each harvested row the harvester went back along the harvested path about 8 m. Then three 650 mm × 385 mm metal frames put in three places, then kernals and ears gathered in order to be counted (A). Then header loss was calculated using the following expression (Bawatharani *et al.*, 2015).

Header loss, kgha^{-1}= (A - B) × 1000 grain weight × 4 × 10^{-2} (3)

(Grain weight for 1000 finger millet grains = 41.53 g)

$$\text{Header loss, percent} = \frac{\text{Header loss}}{\text{P}} \times 100 \qquad (4)$$

Where,
A = total grains and ears counted at the head
B = total grains and ears counted in the natural loss section
P = total yield of the field, kgha^{-1}

4. Statistical analysis
The data recorded were analyzed using AGRESS software to determine the significance of factors using ANOVA table

4.1 Effect of reel rotational speed at selected levels of reel mounting height and forward speed on harvesting efficiency and header loss
It is noticed that higher harvesting efficiency of 89.86 per cent was achieved for 30 rpm reel rotational speed and 40 cm reel mounting height (Figure 3). The minimum of 76.48 per cent harvesting efficiency was obtained at reel rotational speed of 40 rpm at reel mounting height of 45 cm. 1.4 and 3.84 per cent reduction of harvesting efficiency was observed as 35 and 40 rpm reel rotational speed when compared with 30 rpm reel rotational speed. This is due to the fact that at higher reel rotational speed the reel failed to push the crop against the cutter bar and at lower reel rotational speed, the frequency of reel tine bar is less hence more crops sliped away from the cutter bar as the harvester moved forward.

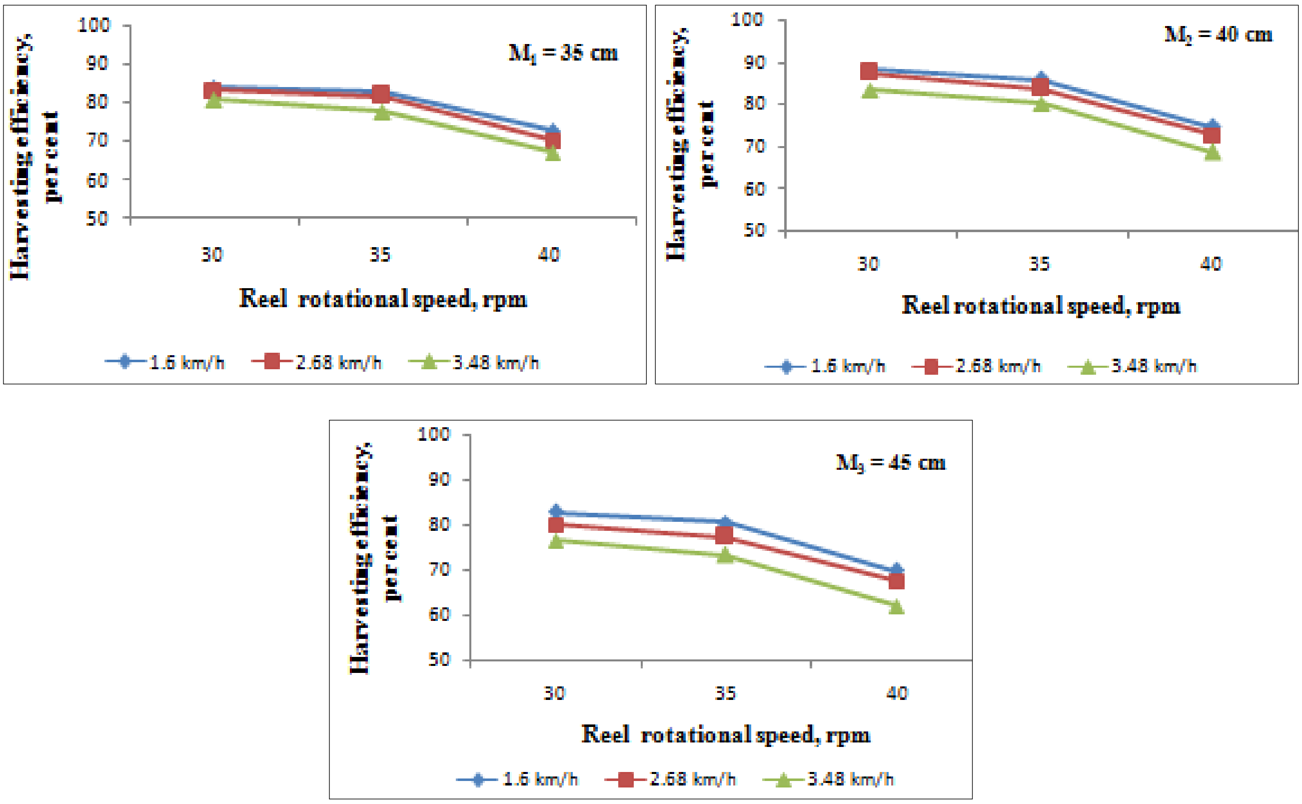


Fig 3: Effect of reel rotational speed at selected levels of reel mounting height and forward speed on harvesting efficiency

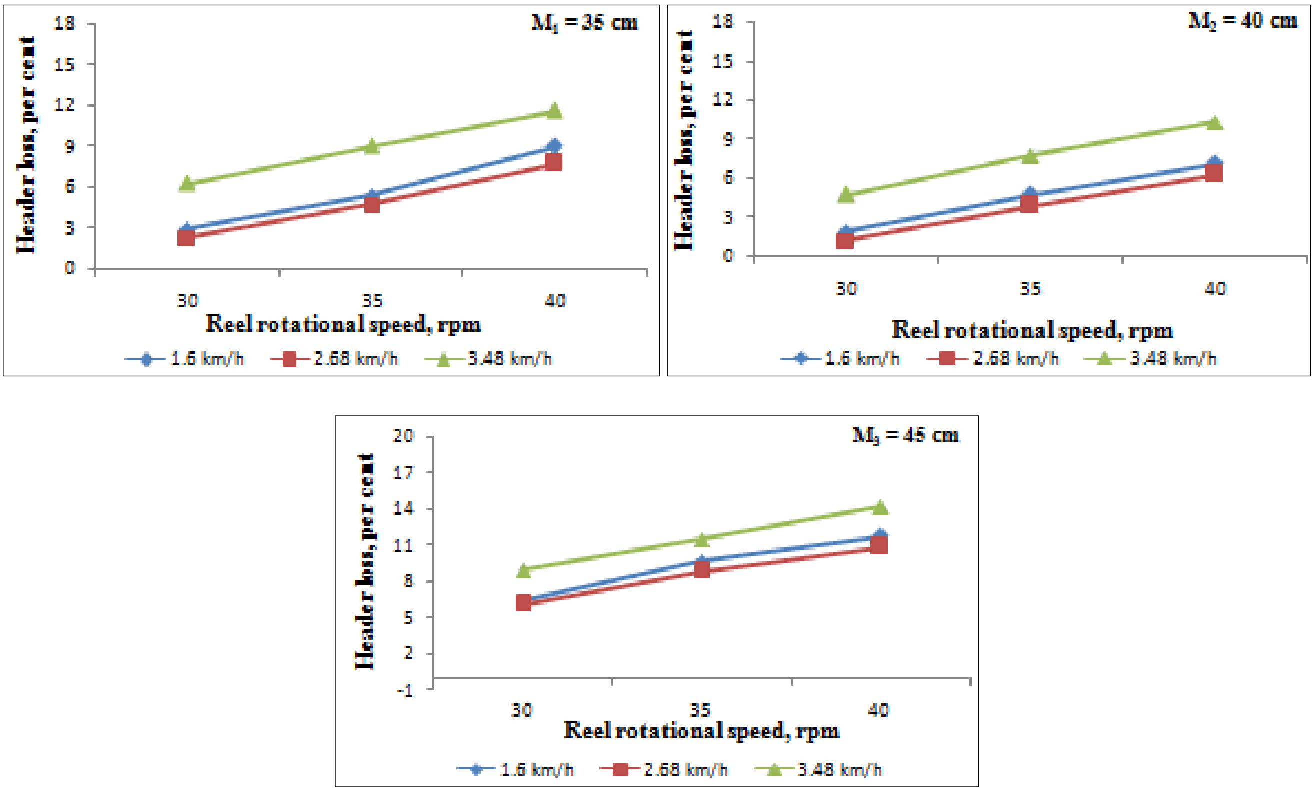


Fig 4: Effect of reel rotational speed at selected levels of reel mounting height and forward speed on header loss

There observed a minimum and maximum header loss of 4.75 and 16.57 per cent at 30 and 40 rpm reel rotational speed (Figure 4). The increase in reel rotational speed caused increase in header loss. This due to the fact that at low reel rotational speed the fingers fails to collect and direct the crop to the header. When reel rotational speed was increased fingers beats the earheads strongly and the earheads thrown behind the harvester which lead to an increase in header loss.

4.2 Effect of reel mounting height at selected levels of reel rotational speed and forward speed

It is noticed that 4.6 per cent and 6.7 per cent reduction of harvesting efficiency was observed at 35 cm reel mounting height and 45 cm reel mounting height when compared to 40 cm reel mounting height (Figure 5). This might be due to increase in clearance between the cutter bars and reel which causes failure in holding the lodged crops for cutting

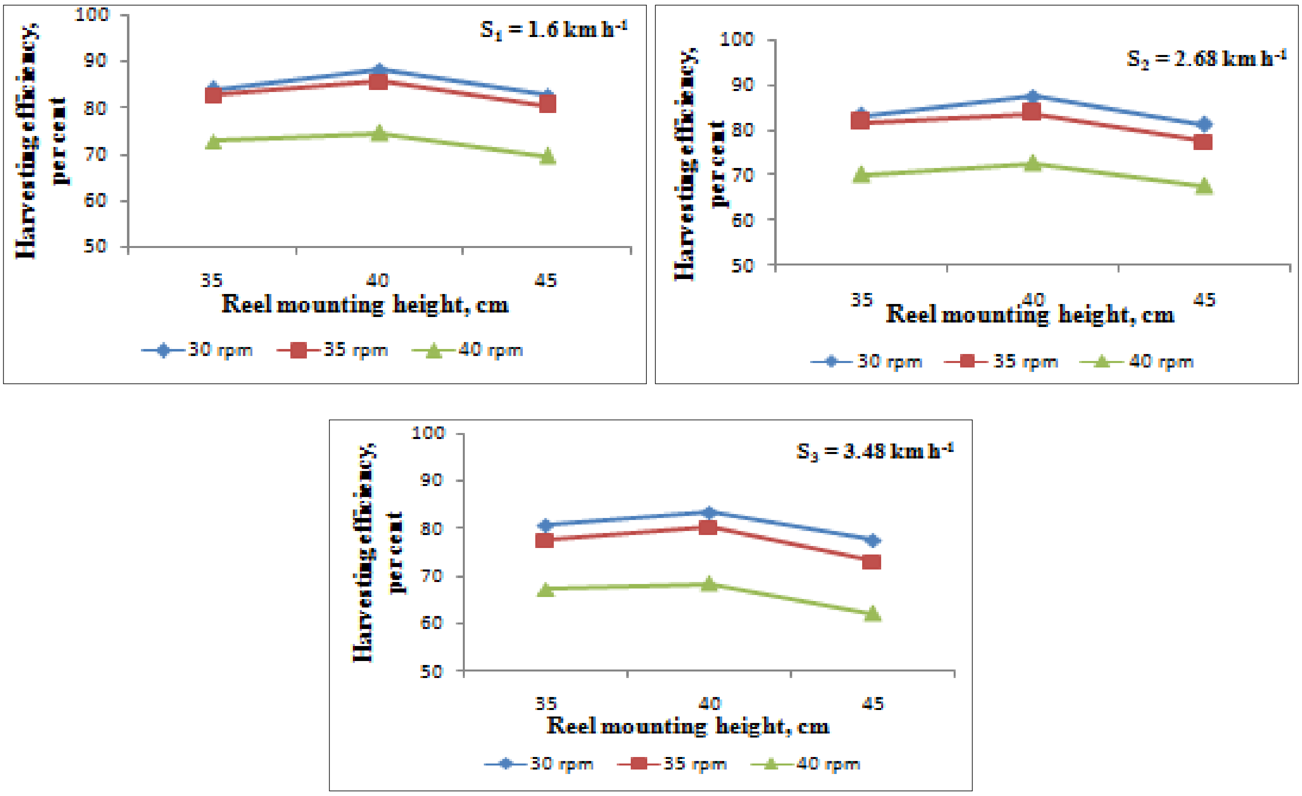


Fig 5: Effect of reel mounting height at selected levels of reel rotational speed and forward speed on harvesting efficiency

It is inferred that 11.4 per cent and 32.9 per cent increase of header loss was observed at 35 cm reel mounting height and 45 cm reel mounting height when compared to 40 cm reel mounting height. This is due to the fact that at high reel mounting height (45 cm) the reel fails to push the plant in to the path of the platform auger which causes the earheads to fall back into the field. This might be due to the reason that, as the reel mounting height increases, the clearance between the cutter bar and reel increases which causes the earheads to fall down due to vibration.

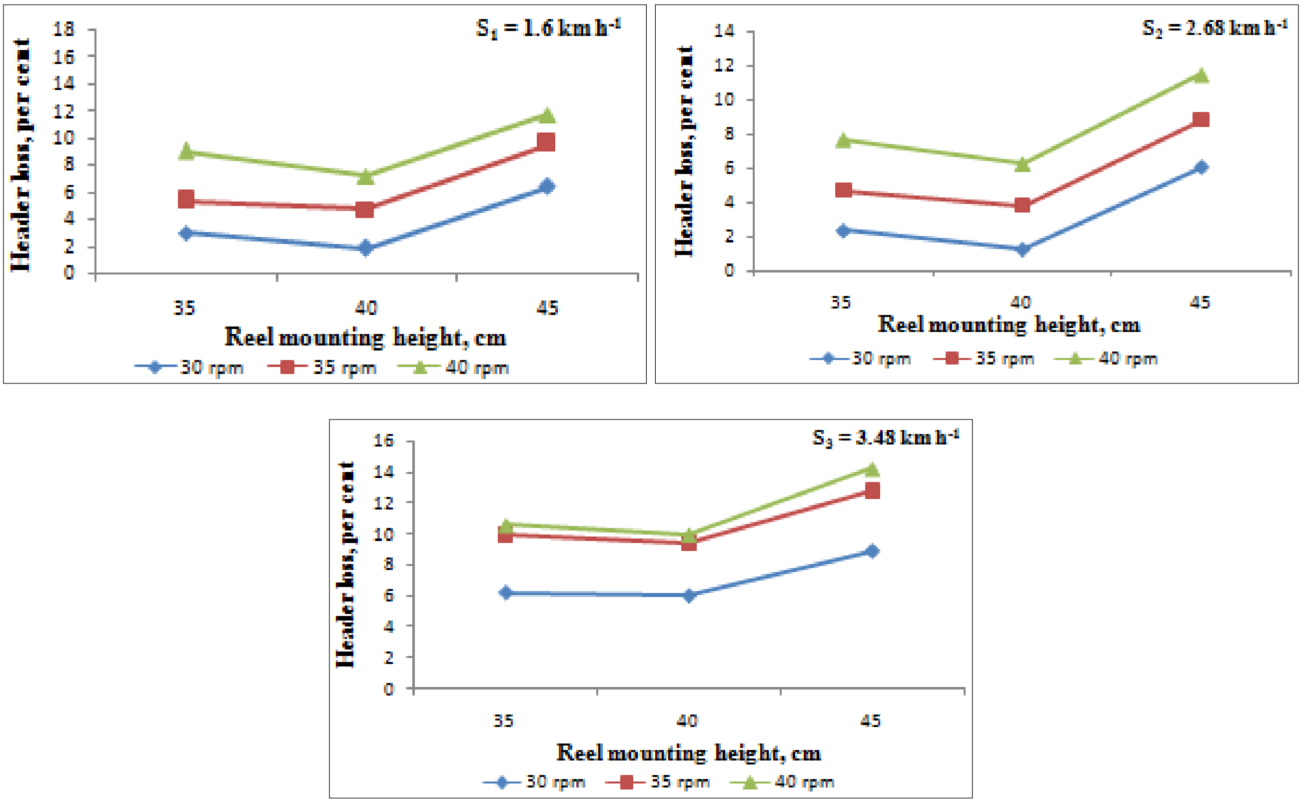
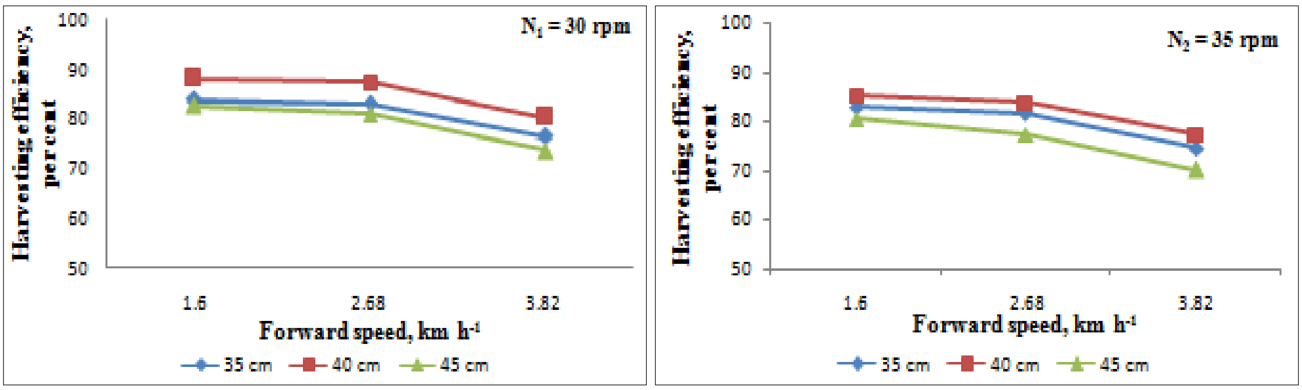


Fig 6: Effect of reel mounting height at selected levels of reel rotational speed and forward speed on header loss

4.3 Effect of forward speed at selected levels of reel rotational speed and reel mounting height

The maximum harvesting efficiency of 91.5 per cent was observed for 1.6 kmh^{-1} forward speed at 30 rpm reel rotational speed (Figure 7). The minimum of 73.88 per cent harvesting efficiency was obtained for 3.48 kmh^{-1} forward speed at 40 rpm reel rotational speed. 1.5 and 9.1 per cent reduction of harvesting efficiency was observed at 2.68 and 3.48 kmh^{-1} forward speed when compared to 1.6 kmh^{-1}. The reduction in harvesting efficiency was due to the increase in forward speed which causes slippage of crops from the cutter bar.



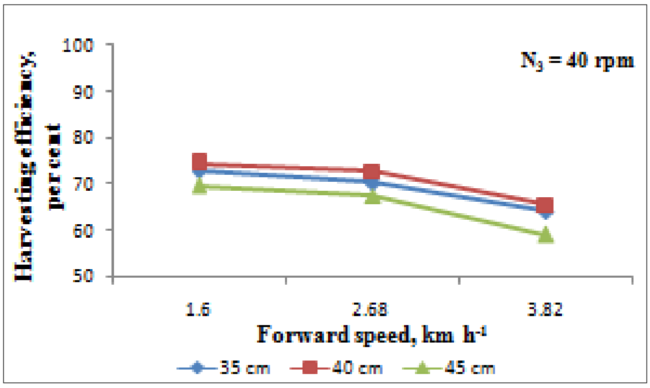


Fig 7: Effect of reel mounting height at selected levels of reel rotational speed and forward speed on harvesting efficiency

The effect of forward speed on header loss was highly influencing and indicated maximum header loss of 16.17 per cent at 3.48 kmh^{-1} forward speed and 40 rpm reel rotational speed. A minimum header loss of 5.01 per cent was observed at 1.6 kmh^{-1} forward speed and 30 rpm reel rotational speed. It is observed that increasing the forward speed increases vibration in the upper cutting unit which causes increase in header loss.

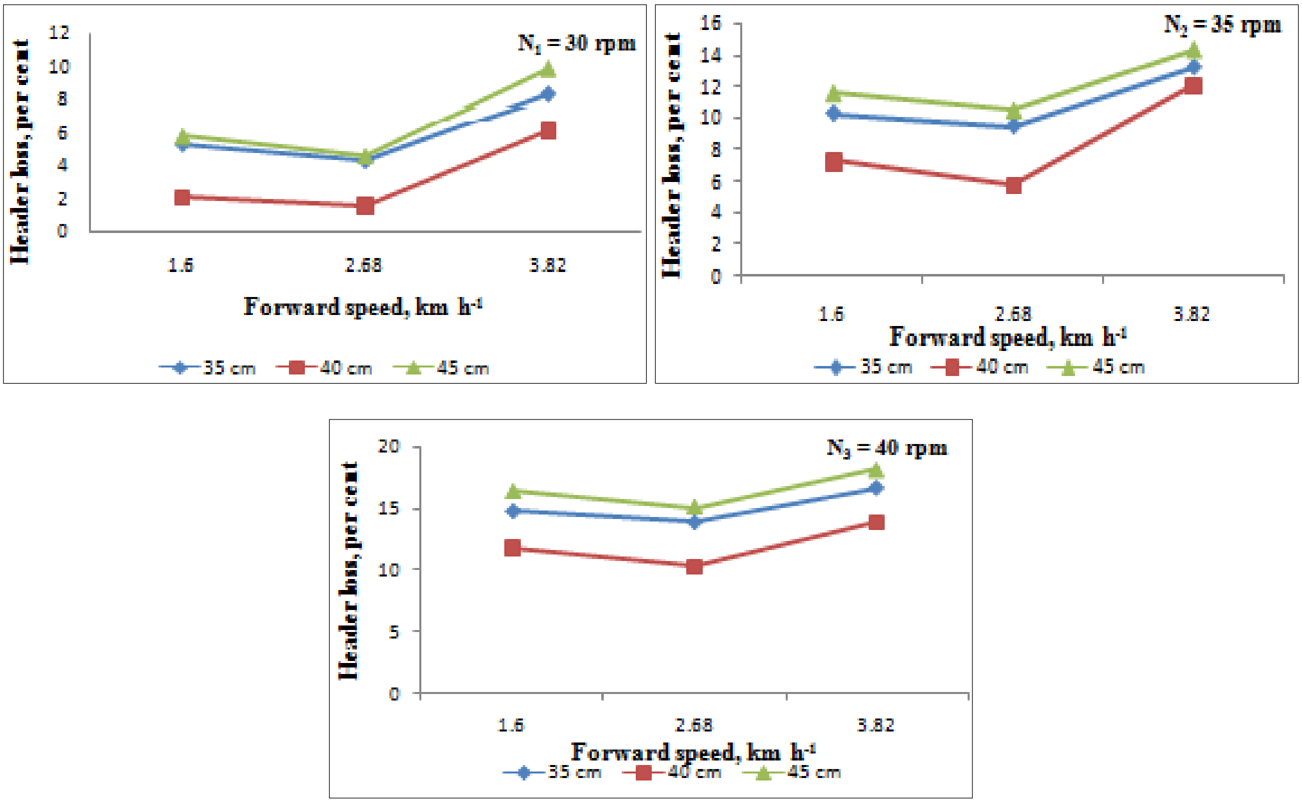


Fig 8: Effect of reel mounting height at selected levels of reel rotational speed and forward speed on header loss

Table 2: Analysis of variance for harvesting efficiency

S. No.	SV	DF	SS	MS	F
1	Treatment	26	3710.09	142.69	130.36^{**}
2	Reel rotational speed (N)	2	392.96	1410.06	1288.23^{**}
3	Reel mounting height (M)	2	435.43	217.71	198.90^{**}
4	Forward speed (S)	2	412.61	206.30	188.48^{**}
5	N × M	4	9.33	2.33	2.13^{*}
6	M × S	4	7.15	1.78	1.63^{NS}
7	N × S	4	13.35	3.33	3.05^{*}
8	N × M × S	8	12.06	1.50	1.37^{NS}
9	Error	54	59.10	1.00	
10	Total	80	3769.20	47.11	

C.V = 2.10 per cent, ** = Significant at 5 per cent level, * = Significant at 1 per cent level, ^{NS}= Non- significant

Table 3: Analysis of variance for header loss

S. No.	SV	DF	SS	MS	F
1	Treatment	26	1201.31	46.20	81.13^{**}
2	Reel rotational speed (N)	2	619.87	309.93	544.22^{**}
3	Reel mounting height (M)	2	305.47	152.73	268.19^{**}
4	Forward speed (S)	2	232.29	116.14	203.94^{**}
5	N × M	4	18.77	4.69	8.24^{**}
6	M × S	4	5.50	1.37	2.41^{NS}
7	N × S	4	10.14	2.53	4.45^{**}
8	N × M × S	8	9.24	1.15	2.02^{NS}
9	Error	54	30.75	0.56	
10	Total	80	1232.07	15.40	

C.V = 7.5 per cent, ** = Significant at 5 per ecnt level, ^{NS}= Non-significant

The test results were statistically analyzed for harvesting efficiency and header loss (Table 2). The analysis of factor means revealed that maximum harvesting efficiency and minimum header loss was observed in the combination of $N_1M_2S_2$ after comparing all possible combination of interactions of factors considered. The selected combinations of parameters are 30 rpm reel rotational speed, 40 cm reel mounting height and 2.68 kmh^{-1} forward speed.

Conclusion

It is concluded that the harvesting efficiency was significantly affected by the reel rotational speed, mounting height of reel and forward speed. Comparing the best combinations of machine and operational parameters, the maximum harvesting efficiency of 91.50 per cent was achieved at the combination of 30 rpm reel rotational speed, 40 cm mounting height of reel and 2.68 kmh^{-1} forward speed with 1.25 percent header loss.

Acknowledgments

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