



Performance evaluation of modified BAU self-propelled reaper for paddy

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Abstract

Bangladesh has an agrarian economy in which paddy is the dominant crop. Significant amount of field losses of paddy occurs every year due to natural calamities and shortage of time during harvesting period. During this study, a modification was done on locally developed BAU self-propelled reaper and its performance was compared with manual harvesting system of paddy. Several experiments were conducted in *Boro* paddy (April–May 2017) and *Aman* paddy harvesting (November–December 2017) at BAU farm of Bangladesh Agricultural University after necessary modification works in the workshop. An experiment was also conducted on *Aman* paddy in 2017 at BAU farm for determining manual harvesting cost. The technical and economic performances of the modified BAU self-propelled reaper were determined based on the field experiments. Results reveal that average fuel consumption, effective field capacity and field efficiency were 2.71 L/ha, 0.255 ha/h and 77.27%, respectively for the modified BAU self-propelled reaper, and 2.88 L/ha, 0.25 ha/h and 75.76%, respectively for the existing BAU self-propelled reaper. These results indicated that field performances of modified BAU self-propelled reaper were better than that of the existing BAU reaper. Paddy harvesting cost was found 916 Tk/ha for modified BAU self-propelled reaper and 9200 Tk/ha for manual harvesting system. Benefit cost ratio of the modified BAU self-propelled reaper was 2.18. Considering the technical and economic performances, modified BAU self-propelled reaper was found suitable than the existing BAU reaper. So, the modified BAU self-propelled reaper may be introduced in Bangladesh in commercial basis.

Introduction

Bangladesh is basically an agricultural country. World Bank (2016) reported that more than 70 percent of Bangladesh's population and 77 percent of its workforce lives in rural areas. Nearly half of all of Bangladesh's workers and two-thirds in rural areas are directly employed by agriculture, and about 87 percent of rural households rely on agriculture for at least part of their income. Paddy is a major cereal crop in agriculture that contributes to national food security and socio-economic development. In 2015–16 fiscal year, agriculture contributed 17% of GDP (BBS, 2016). Harvesting of paddy is traditionally done by sickle by both male and female farmers in Bangladesh (Pandey and Devnani, 1985). Traditional manual harvesting of paddy using a sickle is a quite tedious and labor intensive job. Due to migration of labor in nonagricultural sectors, shortage of labor and cost for paddy harvesting are serious problems in peak harvesting season. Zhang *et al.* (2014) mentioned about a progressive shrinking of rural labor availability, as workers migrate to cities or abroad to engage in more remunerative employment, particularly in the garments and construction sectors. Timely harvesting operation of paddy is a crucial and important process for quantity, quality and production cost of paddy. Significant amount of field losses of paddy occurs in every year due to natural calamities, shortage of time during harvesting period and delayed harvesting. Samon and Duff (1973) reported that 5, 7 and 10 days delayed harvest resulted in 3, 6 and 11% decrease in paddy yield, respectively. Iqbal *et al.* (1980) developed

mathematical models for the harvesting and threshing losses of wheat in the field. They found that manual harvesting losses increase linearly with time, ranging from 3% in the first week to 7% in the third week after ripening of the crop.

Mechanization of agricultural activities is to increase the labor productivity, cropping intensity and cost reduction. Hossain *et al.* (2015) showed that average time, cost and grain that could be saved by using combine harvester over manual methods are 97.50%, 35.00% and 2.75%, respectively. Mechanization also helps in better management of farm by proceeding more free time for planting of next crop. Meisner *et al.* (1997) showed that a reaper is 14 times more efficient than a daily laborer in cutting and placing cereals in the field. Appropriate farm mechanization has been emphasized as an important policy and development goal in Bangladesh (Mandal, 2002, 2014; Zhang *et al.*, 2014). So, suitable machinery, especially harvesting machinery, is a crying need to increase production with less drudgery.

Mechanical harvesting of paddy by using a reaper minimizes the time, drudgery, labor involvement, harvesting losses and increases the cropping intensity. In Bangladesh, all the imported reapers are operated by petrol engine. Generally, retail price of petrol is 90 Tk/L and that of diesel is 65 Tk/L. For reducing operating cost, a reaper, called BAU self-propelled reaper, was developed (Hossain, 2003) through REFPI project during 1997-2003. The reaper was run by diesel fuel-

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operated 5 hp engine (Model: Z175F-1). In today's world, where fuel price is increasing as a consequence of spiraling demand and diminishing supply, it is necessary to choose a cost-effective fuel to meet the needs. Diesel is available in all places, but petrol is not available in all local markets. The diesel engine has proved to be extremely efficient and cost effective. Accessories of diesel engine are also available in the local market and the cost of diesel engine accessories is much cheaper than petrol engine.

Field performance of the existing BAU reaper was not satisfactory due to several mechanical problems like straw clogging during the operation because of lower cutter bar speed than forward speed and slipping problem of cage wheel. In addition to these, there were also observed some minor problems like weight unbalanced, turning problem due to the clutch adjustment, excessive vibration, excessive noise, and improper adjustment of star wheel and spring. Therefore, the main objectives of the study were to assess the present status of the existing BAU self-propelled reaper through field operations and to modify the reaper and test its field performance.

Materials and Methods

Study location

The modification works of BAU self-propelled reaper were done in the Engineering workshop under the Department of Farm Power and Machinery of Bangladesh Agricultural University and the field experiments were conducted at the BAU farm, Mymensingh, Bangladesh.

Problems associated with existing BAU self-propelled reaper

In Aman/2016, the existing BAU self-propelled reaper was tested to harvest paddy at BAU farm after long time (about 10 years) idle conditions of the reaper. During idle period, the reaper was not used due to several functional problems like (i) weight unbalanced, (ii) straw clogging with cutter bar and chain, (iii) improper adjustment of belt and pulley, (iv) slipping problem due to cage wheels, (v) poor condition of the prime mover (diesel engine), (vi) improper adjustment of vertical power transmission shaft with dog sprocket, (vii) improper adjustment of star wheel and spring and (viii) lower cutter bar speed than that of forward speed. Some identified problems during Aman/2016 paddy harvesting are shown in Fig. 1.

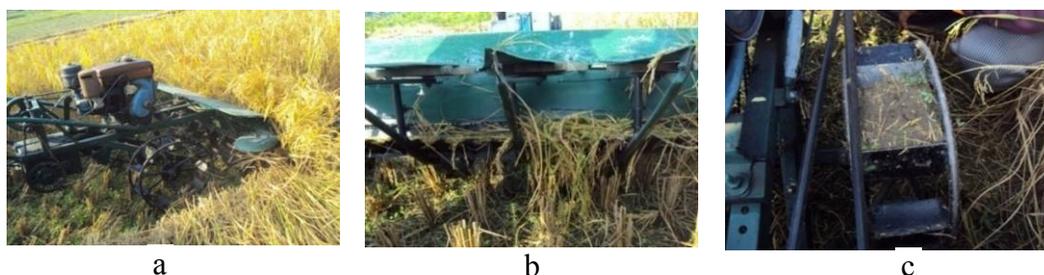


Fig. 1. Photographic views of Aman/2016 harvesting: a) using existing BAU self-propelled reaper b) straw clogged with cutter bar and chain, c) iron cage wheel of reaper

Modification of BAU self-propelled reaper

Identified problems were minimized in the engineering workshop under the Department of Farm Power and Machinery, Bangladesh Agricultural University. Iron cage wheels were changed by tyre wheel for better traction and less slipping to reduce forward speed and avoid straw clogging. For increasing cutter bar speed, 4 inch cutter bar pulley was replaced by 4.5 inch diameter pulley. An additional support like an idler pulley was

incorporated with belt power transmission system, which increased belt tension for proper power transmission. Star wheels and springs were adjusted after dismantling those parts for proper rotation and transferring of straw during harvesting. Vertical power transmission shaft was welded and adjusted with dog sprocket. Several sections of the reaper were dismantled and adjusted for balancing the weight of the reaper. Some modification activities before Boro/2017 paddy harvesting are shown in Fig. 2.



Fig. 2. a) Iron cage wheel replaced by tyre wheel, b) cutter bar pulley changed, c) old engine was replaced by new one, d) star wheel adjustment in engineering workshop, and e) belt and pulley setting adjustment

Selection of pulley

At first, paddy was harvested using BAU self-propelled reaper with 114.3 mm (4.5") pulley, but the ratio of cutting and forward speed of reaper was found 1.01. It was decided to increase the cutter bar speed of the reaper. As there were no facilities for changing the cutting speed through gear box mechanism, the cutting

speed was changed by varying the pulley size at second transmission shaft. For that three pulleys were purchased from local market. The sizes of the pulleys were 114.3 (4.5"), 127 (5") and 139.7 (5.5") mm. Internal bore and slot were made for each pulley in the workshop to fit them with the transmission shaft. Three pulleys of different sizes are shown in Fig. 3.

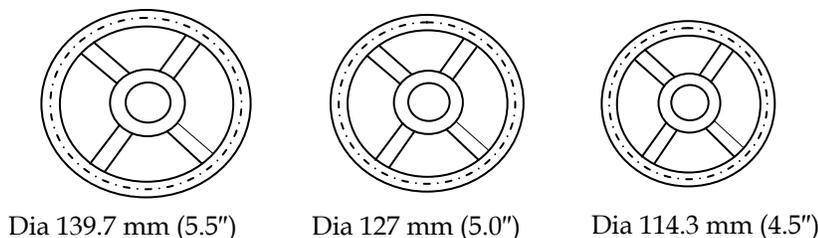


Fig. 3. Front views of three different sizes pulleys (139.7, 127 & 114.3 mm)

Harvesting operations

In Bangladesh, mainly two types of harvesting operation are in practice: manual harvesting and mechanical harvesting systems. So, two methods of paddy harvesting were used at the experimental sites during Aman/2016, Boro/2017 and Aman/2017 paddy harvesting seasons. These were: a) traditional method (manually using sickle) and b) modern/mechanical method (using existing and modified BAU self-propelled reaper).

Manual harvesting cost and loss

For determination of manual harvesting cost and losses, 3 (three) plots were selected and all plots were harvested

by manually using sickle as shown in Fig. 4. For cost calculation, required harvesting time and labor were counted and finally calculated based on the appropriate mathematical equations. For comparison of harvesting loss between manual and mechanical systems, two types of losses were measured, i.e. i) shatter and ii) cutter bar losses. Matured drop paddy from the panicle caused by bird, wind, rats, and handling operations were collected and measured. After completing the harvesting operation, uncut plant stems were also collected carefully and kept on the polythene sheet for estimating cutting loss as shown in Fig. 5.



Fig. 4. Manual harvesting by sickle at BAU Farm



Fig. 5. Collection of dropped paddy and uncut stem

Paddy harvesting using modified BAU self-propelled reaper

Field performance of the BAU self-propelled reaper was tested at BAU farm during Aman/2016, Boro/2017 and Aman/2017 seasons after necessary modifications of the reaper.

Performance evaluating indicators of BAU self-propelled reaper

For the technical and economic performances analysis of mechanical harvesting of paddy, the indicators considered were: (i) operational time, (ii) working speed, (iii) field capacity, (iv) cutting efficiency, (v) labor requirement for harvesting, (vi) grain yield, (vii) grain losses, and (viii) fuel consumption.

Field capacity and field efficiency

Field capacity and field efficiency were determined (Hunt, 1995) as follows:

$$\text{Effective field capacity (ha/h), } C_{\text{eff}} = \frac{A}{T} \dots\dots\dots (1)$$

where C_{eff} = effective field capacity (ha/h)
 T = total time for the reaping operation (including lost time), h
 A = area coverage, ha

$$\text{Theoretical field capacity (ha/h), } C_{\text{th}} = \frac{wS}{10} \dots\dots\dots (2)$$

where C_{th} = theoretical field capacity (ha/h)
 S = rated forward speed of machine (km/h)
 w = rated width of the cutter bar (m)

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$$\text{Field efficiency (\%), } e = \frac{C_{eff}}{C_{th}} \times 100 \dots\dots\dots(3)$$

Cutting efficiency

Cutting efficiency was determined (Hunt, 1995) as

$$\text{Cutting efficiency (\%)} = \frac{e-d}{e} \times 100 \dots\dots\dots (4)$$

where e = number of plant per square meter before reaping and d = number of uncut plant per square meter.

Cost calculation for mechanical harvesting

Cost analysis for BAU self-propelled reaper for the harvesting of paddy, especially cost of operation of the machine, was determined by considering fixed cost and variable cost. Harvesting cost and time of mechanical harvesting system were also compared with manual harvesting system.

Fixed costs

The fixed cost is the cost, which is involved irrespective of whether the machine is used or not. This cost includes i) depreciation cost, ii) interest on investment, and iii) taxes, shelter and insurance.

i) Depreciation cost

Depreciation is the reduction in value of a machine with the passes of time. Depreciation cost was calculated by straight line method (Hunt, 1995) as follows:

$$\text{The annual depreciation, } D = \frac{P - S}{L} \text{ (Tk/yr)} \dots\dots\dots(5)$$

where P = purchase price, Tk, S = selling price, Tk. and L = time between buying and selling, yr.

ii) Interest on investment

Interest on the investment in a farm machine is a legitimate cost, since money spent in buying a machine cannot be used for other productive enterprises, it was calculated by Straight Line Method (Hunt, 1995) as

$$\text{Interest on investment, } I = \frac{P + S}{2} i \dots\dots\dots(6)$$

where P = Purchase price, Tk, S = Re-sale value, Tk, and i = annual interest rate.

Cost saving for using reaper (Tk/ha) = Cost for manual method (Tk/ha) – cost for harvesting through reaper (Tk/ha)

$$\text{Cost saving (\%)} = \frac{\text{Cost for manual harvesting (Tk/ha)} - \text{Cost for mechanical harvesting (Tk/ha)}}{\text{Cost for manual harvesting (Tk/ha)}} \times 100$$

Results and Discussion

Performance of BAU self-propelled reaper

After using existing BAU self-propelled reaper and modified BAU self-propelled reaper, the measured average forward speed, fuel consumption, effective field capacity, theoretical field capacity and field efficiency are presented in Table 1. According to the results mentioned in Table 1, field performances of modified BAU self-propelled reaper was found better than that of existing BAU self-propelled reaper. Improved performance was obtained due to mechanical

iii) Taxes, shelter and insurance

In the experiment, shelter, tax and insurance, $STI = 2.5\%$ of P was considered for calculating fixed cost of harvesting machine (Hunt, 1995).

Total fixed cost

Total fixed cost was estimated (Hunt, 1995) as

$$\text{Total fixed cost (Tk/yr)} = D + I + STI \dots\dots\dots(7)$$

$$\text{Fixed cost (Tk/ha)} = \frac{\text{Total Fixed Cost (Tk/Yr)}}{\text{Total Area Coverage (ha/Yr)}}$$

Variable costs

Fuel cost, oil cost, labor cost and repair & maintenance cost were determined (Barger *et al.*, 1987) as

$$\text{Oil cost, O (Tk/ha)} = 15\% \text{ of fuel cost, } F \dots\dots\dots(8)$$

$$\text{Fuel cost, F (Tk/ha)} = \frac{\text{Fuel consumed (L/day)} \times \text{Price (Tk/L)}}{\text{Area covered (ha/day)}} \dots\dots\dots (9)$$

$$\text{Lobor cost, L (Tk/ha)} = \frac{\text{Sum of wages of labor (Tk/day)}}{\text{Area covered (ha/day)}} \dots\dots\dots (10)$$

$$\text{Repair and maintenance cost, R\&M (Tk/ha)} = 0.025\% \text{ of purchase price, } P \dots\dots\dots(11)$$

Total variable cost was determined using Eq.12 and total harvesting cost was determined using Eq.13.

$$\text{Total variable cost} = (F + O + L + R\&M) \text{ Tk/ha} \dots\dots\dots(12)$$

$$\text{Total cost of harvesting (Tk/ha)} = \text{Fixed cost (Tk/ha)} + \text{Variable cost (Tk/ha)} \dots\dots\dots(13)$$

Cost calculation for manual harvesting

Manual harvesting cost depends on labor rate and number of labor required for the area to be harvested. It was determined using Eq.14.

$$\text{Total cost (Tk/ha)} = \text{Wage of laborer (Tk/man)} \times \text{No. of laborer (man/ha)} \dots\dots\dots(14)$$

Cost saving by mechanical harvesting

The costs of two different paddy harvesting methods like reaper and manual harvesting systems were compared to determine the benefits of mechanical harvesting system over manual harvesting.

modification of belt, pulley, star wheel adjustment, balance adjustment. Replacement of new wheel and diesel engine with the modified reaper was also supported to obtain improve performance.

Field capacity and field efficiency

After modification works, field capacity and field efficiency were determined for the different pulley sizes as provided in Table 2. There is no significant difference in field capacity and field efficiency for different pulley sizes but comparative better performances were found for the pulley size 5.5 inches.

Table 1. Field performance of BAU self-propelled reaper

Harvesting machine	Obs. No.	Forward speed, km/h	Fuel consumption, L/ha	Effective field capacity, (ha/h)	Theoretical field capacity, ha/h	Field efficiency, %
Modified BAU self-propelled reaper	1	2.73	2.87	0.2480	0.3276	75.70
	2	2.78	2.69	0.2578	0.3336	77.28
	3	2.79	2.56	0.2618	0.3348	78.20
	Avg.	2.77	2.71	0.2550	0.3320	77.06
Existing BAU self-propelled reaper (Hossain, 2003)		2.75	2.88	0.25	0.33	75.76

Table 2. Comparison of field performances on the basis of using different sizes pulley

Pulley size (inch)	Effective field capacity, C_{eff} (ha/h)			Theoretical field capacity, C_{th} (ha/h)			Field efficiency, (%)
	Area reaped, A (m^2)	Time, T (min)	Effective field capacity, A/T (ha/h)	Forward speed, S (km/h)	Effective width, w (m)	Theoretical field capacity, wS/10 (ha/h)	
4.5	1418.32	34.31	0.2480	2.73	1.2	0.3276	75.70
5.0	730.45	17.00	0.2578	2.78	1.2	0.3336	77.28
5.5	752.85	17.25	0.2618	2.79	1.2	0.3348	78.20

Effect of cutting and forward speeds on throwing performance

A comparative analysis for cutting and forward speeds of modified BAU self-propelled reaper during paddy harvesting is given in Table 3.

Straw cutting performance of the reaper during harvesting operation was not affected using different cutting speeds as mentioned in Table 3. Throwing performance was affected by the ratio of cutting and forward speeds. Throwing performance increases gradually with increasing the ratio of cutting and forward speeds. Cutting performance was measured by counting the uncut stem and the roughness of cutting

parts, on the other hand throwing performance was measured by observing the throwing and dropping of cutting straw or stem in line at the field without hazard. The throwing performance was found more satisfactory for the ratio of cutting and forward speeds 1.21.

Effect of pulley size on cutting efficiency

Cutting efficiency increased with increased pulley sizes (4.5", 5.0", 5.5" dia.) (Table 4). A pulley having larger diameter makes more cutting speed with throwing performance as shown in Fig. 6. In the field, higher cutting and throwing speeds help to reduce the cutting losses. The rates of uncut straw reduced with increase of pulley size of BAU self-propelled reaper.

Table 3. Average forward speed, cutting speed and ratio of cutting and forward speed

Pulley size (inch)	Obs. No.	Distance travelled (m)	Time (min)	Forward speed, V_f (m/min)	Avg. forward speed, V_f (m/min)	Cutting Speed, $V_c = \frac{2Ln_{11}}{1000}$ (m/min)	Ratio, $R_c = V_c/V_f$
4.5	1	39.36	0.85	46.31	45.66	45.9	1.01
	2	18.56	0.407	45.60			
	3	38.15	0.846	45.08			
5.0	1	26.26	0.55	47.75	46.14	51.0	1.11
	2	57.93	1.3	44.56			
	3	53.96	1.17	46.12			
5.5	1	40.52	0.870	46.57	46.50	56.11	1.21
	2	18.36	0.385	47.68			
	3	37.42	0.827	45.25			

Table 4. Variation of cutting efficiency with pulley size

Pulley size (Inch)	No of plant per m ² before reaping (e)	No of uncut plant /m ² (d)	Cutting	Average Cutting efficiency
			efficiency (%)= $\frac{e-d}{e} \times 100$	
4.5	396	1	99.74	99.76
	417	1	99.76	
	414	2	99.52	
5.0	396	1	99.75	
	389	1	99.74	
	414	1	99.76	
	406	1	99.76	
5.5	359	0	100	
	398	1	99.75	



Fig. 6. Harvesting of paddy using 5.5" pulley

Harvesting cost saving by modified BAU self-propelled reaper

Estimated manual and mechanical paddy harvesting costs are presented in Table 5. Manual paddy harvesting cost was 9200 Tk/ha which depends on the total number of required labors/ha and the labor wages rate. On the

other hand, mechanical paddy harvesting cost using the modified BAU self-propelled reaper was 916 Tk/ha (including fixed cost & variable cost). Compared to manual harvesting, mechanical harvesting saved 90% cost as compared in Table 5.

Table 5. Harvesting cost saving using the modified BAU self-propelled reaper

Manual harvesting cost			Modified BAU self-propelled reaper			Cost saved over manual method (%)
Total no. of labor/ ha	Labor wage, Tk/labor	Total cost (Tk/ha)	Fixed cost (Tk/ha)	Variable cost (Tk/ha)	Total cost (Tk/ha)	
23	400	9200	145	771	916	90

Benefit cost ratio (BCR)

The benefit cost ratio (BCR) is an important factor to measure the profitability of the reaper. If the value of benefit cost ratio (BCR) is greater than unity, then it will be economically accepted. The benefit cost ratio (BCR) of the modified reaper was calculated from the gross return (244800 Tk/yr) dividing by the total harvesting cost (112118 Tk/yr). Based on the calculation, BCR of BAU self-propelled reaper was found 2.18 which indicates that using of BAU self-propelled reaper is profitable.

Average shatter, cutter bar and total harvesting losses were found a) 0.22%, 0.24% and 0.46%, respectively for BAU self-propelled reaper and b) 0.73%, 0.62% and 1.35%, respectively for manual harvesting. All losses were more in manual harvesting system.

Field losses for mechanical and manual harvesting systems

The average harvesting losses, including shatter and cutter bar losses, of modified BAU self-propelled reaper and manual harvesting system are given in Table 6.

Table 6. Harvesting losses using modified BAU self-propelled reaper and manual harvesting

Method	Shatter loss, %	Cutter bar loss, %	Total loss, %
Modified BAU self-propelled reaper	0.22	0.24	0.46
Manual harvesting	0.73	0.62	1.35

Conclusion

Technical and economic performances of modified BAU self-propelled reaper were found better than that of existing BAU self-propelled reaper. Straw cutting

performance of the reaper during harvesting operation was not affected using different cutting speeds. On the other hand, throwing performance increases gradually with increasing the ratio of cutting and forward speeds. Compared to manual harvesting, mechanical harvesting saved 90% cost. BAU self-propelled reaper also saved field losses of paddy in comparison to manual harvesting system. Based on the all calculations and analysis, BAU self-propelled reaper will be profitable for farmers.

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