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Performance evaluation of power-operated reapers for harvesting rice at farmers' field

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Abstract

Harvesting is one of the major labor intensive works in rice cultivation. Appropriate harvesting machinery is urgently needed to reduce labor and production costs. Production cost of rice becomes high due to labor shortage and high wage rate during harvesting time. Techno-economic performance of Korean self-propelled reaper (KR), China self-propelled reaper (CR) and BRRI reaper (BR) were evaluated in order to identify the field constrains and problems of the reapers at Mithapukur of Rangpur, Bangladesh during Aman season of 2013. The actual field capacities of the KR, CR and BR were found 0.18, 0.17 and 0.15 ha $h^{-1}$with the corresponding field efficiency of 55, 68 and 56%, respectively. The variation of field capacity among the models was due to turning time losses, weight of the reaper and operator's skill. The fuel consumption of the reapers was 4.11, 2.61 and 8.39 l ha^{-1} for KR, CR and BR, respectively. The shattering loss of paddy harvesting was 1.66, 1.50 and 1.45% for KR, CR and BR, respectively. The break-even area of the reapers was 9.15, 7.82 and 8.43 ha yr^{-1} for KR, CR and BR, respectively. It is evident that the reaper could be used successfully as labor saving and user friendly technology to eliminate post-harvest problems in Bangladesh.

Introduction

Bangladesh is an agriculture based country and its most of the people earn their livelihoods from farming and agriculture-related activities. Total population of Bangladesh is estimated to be 159.9 million (BBS, 2016). The population of Bangladesh is still growing and is expected to reach 200 million by 2050 (UN World Population Prospects, 2012). On the other hand, the amount of cultivable land per capita is decreasing due to various non-agricultural activities such as increased industrialization and urbanization. Rice (*Oryza sativa L.*) is the main staple crop of Bangladesh accounting for 76% of total cropped area and 95% of cereals production. Bangladesh is the 4th largest rice producing country in the world due to the use of high yielding varieties (HYV) and modern rice production technology instead of local variety and traditional production technology. Bangladesh is now producing about 34.86 MT of paddy to feed the growing population (Kabir *et al.*, 2015). Rice production of Bangladesh needs to be increased to feed the growing population of the country with a limited land resource by reducing post-harvest loss in every stage of production.

Most of the farmers of the country use traditional method to harvest their crop. As a result, excessive loss occurs due to the use of traditional method and delayed harvesting of paddy. Post-harvest loss occurs at every stage in rice production supply chain such as harvesting, threshing and cleaning, drying, storage, processing/ milling, marketing and consumer level. The amount of post-harvest loss in traditional process is: cutting and handling 1–5%, sun drying 3–5%, open storage 5–10% and village milling 20–30%.Whereas such loss in modern process is: combine harvesting and machine threshing 1–5%, mechanical drying 1–2%, sealed storage 1–2% and commercial milling 5-10% (Hodges *et al.*, 2011). The post-harvest loss of rice in Bangladesh is approximately 14% (Bala *et al.*, 2010): cutting 1.06 – 6.5%, handling and transport 0.63 to 6.0%, threshing, 1.65 to 2%, drying 1.56 to 5% and storage 3.05 to 7.5%.

Therefore, it is essential to introduce mechanical harvester with simple operating system that will harvest paddy in both wet and dry land condition. Power tiller-mounted reaper is an alternative to harvest rice and wheat within a short time. This technology is being popularizing in Bangladesh through BRRI, BARI, DAE and other Govt. and non-Govt. organizations taking effective measures about functional constraints (maneuverability, excessive weight, etc.). Reaper is not the integral part of the power tiller. It is attached with PT through additional attachments like frame, clutch, pulley, string and lever. Actually, power tiller is not designed to attach reaper in front of its PT. The weight of reaper attachment is about 90 kg. Additional measures have to be taken for balancing total weight. In addition, more turning space is required for PT-mounted reaper of long size. To overcome the turning and weight balance problems, a self-propelled reaper was developed by BRRI. This reaper was found suitable in the field with some limitations. A self-propelled reaper was collected from Korea under KOICA funded project (2013). This reaper was designed for multipurpose use with the facilities of mounted reaper, tiller, etc. This reaper was not evaluated in Bangladesh conditions. Under this circumstance, the objectives of the study were to compare the performance of three different types of reaper, and to identify field constraints and problems under Bangladesh condition.

Materials and Methods

Experimental site

The experiment was conducted to evaluate the performance of three different types of reaper at Mithapukur of Rangpur district during Aman season of 2013. Twenty days old seedling of BRRI dhan52 and BRRI dhan49 were transplanted during 25-26 July, 2013 by mechanical rice transplanter. The soil type was sandy loam and soil moisture content ranged from 21.3 to 23.3 % during harvesting.

Experimental design and treatment

The treatments wereT_1= Self-propelled Korean reaper (KR),T_2= China reaper (CR) and T_3= BRRI reaper (BR). RCB design was followed with three replications.

Description of the reapers

The Korean self-propelled reaper, China self-propelled reaper and BRRI reaper were used to conduct the study. The technical specifications of the reapers are presented in Table 1.

Table 1. Technical specifications of the Korean self-propelled reaper, China self-propelled reaper and BRRI reaper

Items	Korean reaper	China reaper	BRRI reaper
Model no	TR 1200B	4C120A	BRRI REAPER 1
Engine type	Petrol engine	Diesel engine	Diesel engine
Reaper type	self-propelled	self-propelled	power tiller-operated
fuel, l h^{-1}	0.8	0.5	1.25
Start mode	Exclusive cartridge starting, recoil type	Handle operated	Handle operated
Weight (without engine), kg	78	77	86
Dimension (L×W×H), cm	154×75×58	153×78×56	152×85×56
Cutting width, cm	120	122	122
Cutting device	Reciprocating knife bar	Reciprocating knife bar	Reciprocating knife bar
Cutting height, cm	10-20	10-20	15-25
Crop release	Left	Right	Right
No. of cutting knife	16	25	25
Fuel type	Petrol	Diesel	Diesel
Engine power, kW	6.43	4.0	16.0

Manual harvesting was also done for cost comparison. Harvesting was done on 20 November 2013 both manually (using sickle) and mechanically using the selected reapers (Fig. 1). Cutting width and height were maintained same for each reaper (Table 1). BRRI power tiller-operated reaper delivers crop in the left side of the machine, whereas the Korean and China self-propelled reapers deliver crop in the right side of the machine.

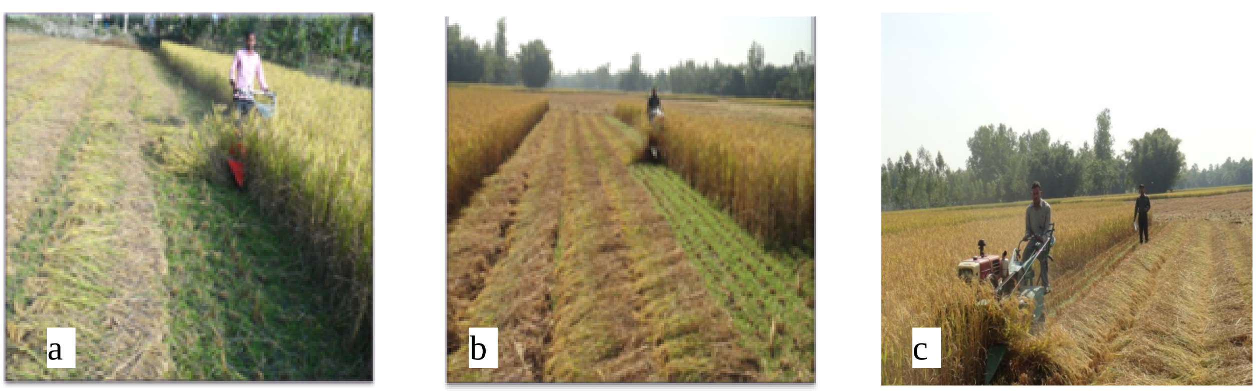

Fig. 1.Paddy harvesting by using different types of reaper: (a) KR, (b) CR and (c) BR

Experimental procedure

Plant height, plant density and soil moisture were measured before harvesting operation with the reaper to control operation speed and cutting height. Soil samples from three different depths (5 cm, 10 cm and 15 cm) were collected to measure the soil moisture. Three small areas (1m × 1m) were selected randomly from each trial plot to determine the plant characteristics, shattering/ pre-harvest and post-harvest losses of paddy for both manual and mechanical harvesting. Plant height was measured from ground level to the end of flag leaf. Harvesting loss (pre-harvest and post-harvest) was measured by marking an area of 1 m² (1m x 1m) in each trial plot with three replications. All the grains lying on the field were picked up carefully from the selected 1 m² area before and after harvesting the paddy. Filled and unfilled grains were also separated to calculate yield of paddy. The collected paddy was cleaned, weighted and added to the pre-harvest and/or post-harvest loss. Moisture content was also measured and weights were adjusted at 14% moisture content. Finally, harvesting loss was calculated based on total loss (pre-harvest and post-harvest losses) to obtain yield of paddy. Missing or remaining tillers after harvesting operation and percentage of damaged hills during operation were counted after harvesting. Operational speed, time of operation and fuel consumption were measured and cost of operation was calculated for both manual and mechanical harvesting. Walking speed was also recorded without any loss to measure the theoretical field capacity of the reaper. Total time of field operation was recorded to measure the actual field capacity of the reaper considering turning loss, operator's personal loss, machine adjustable loss and troubleshooting loss during field operation. Numbers of grains were recorded from the pre-selected 1 m^2 areas before and after field operation. The following formulas were used to measure theoretical field capacity, actual field capacity and field efficiency.

Theoretical field capacity

Theoretical field capacity was measured based on the forward speed and the cutting width of reaper. It was determined using the following formula (Hunt, 1995):

$$\text{Theoretical field capacity (Ct)} = \frac{W \times S}{10} \tag{1}$$

where

Ct= Theoretical field capacity, ha h^{-1}
W= Width of operation, m
S= Forward speed, km h^{-1}

Actual field capacity

Actual field capacity was measured based on area covered and actual time, including turning loss time. It was determined using the following formula (Hunt, 1995):

$$\text{Actual field capacity (Ca)} = \frac{Ta}{Tt} \tag{2}$$

where

C_a = Actual field capacity, ha h^{-1}
T_a = Actual operating time, h
T_t = Total operating time, h

Field efficiency

Field efficiency was measured from the ratio of actual field capacity to theoretical field capacity of the reaper. It was determined using the following formula (Hunt, 1995):

$$\text{Field efficiency (Fe)} = \frac{Ca}{Ct} \times 100 \tag{3}$$

where

C_a= Actual field capacity in ha h^{-1}
C_t= Theoretical field capacity in ha h^{-1}

Harvesting loss

Harvesting loss was determined before and after harvesting by manual cutting and with reaper by using following formula (Pradhan *et al*., 1998):

$$\text{Harvesting loss (HL)} = \frac{W_{hl} - W_{phl}}{Y} \times 100 \tag{4}$$

where

HL = Harvesting loss, %
W_{hl} = Total harvesting loss, g m^{-2}
W_{phl} = pre-harvesting loss, g m^{-2}
Y = Yield of paddy, g m^{-2}

Cost calculation

The harvesting cost with reapers includes fixed cost and variable cost. Comparison was done between manual and mechanical harvesting costs of paddy. The purchase price of the Korean reaper, China reaper and BRRI reaper was Tk.175000,Tk.150000 and Tk.160000, respectively. The useful life of the reapers was considered 8 years. The machine salvage value was considered 10% of the purchase value.

Fixed costs

Fixed costs includes depreciation cost, interest on the machinery investment, taxes, insurance and shelter, and it is a function of purchase price, rate of interest and useful life of the reapers. A straight-line method was used for calculation of depreciation cost(Hunt, 1995).

a) Annual depreciation, $D = \frac{(P - S)}{L}$ (5)

where

D = depreciation, Tk yr^{-1}
P = purchase price of reaper, Tk
S = salvage value, Tk
L = useful life of reaper, yr

b) Interest is a cost on the investment of agricultural machinery and was calculated by:

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

where

P = purchase price of dryer, Tk
S = salvage value, Tk
i = interest rate, %

c) Tax, insurance and shelter costs were considered 3% of purchase price of the reapers.

Total fixed cost, (Tk yr^{-1}) = (D + I + tax, insurance and shelter)

Total fixed cost, (Tk ha^{-1}) = (D + I + tax, insurance and shelter)/(Area covered in ha per h)

Variable cost

Variable cost of a reaper is reflected by the cost of fuel, lubrication, daily service, labor, and repair and maintenance cost for the reapers. These costs increase with increased use of the machine, and vary to a large extent in direct proportion to hours or days of use per year.

a) Labor cost per hour, L = No. of labor x Rate of labor (Tk h^{-1})

b) Fuel cost, F = Price of fuel (Tk l^{-1}) x fuel consumption (l h^{-1})

c) Oil cost per hour, O = 15% of fuel cost

d) Repair and maintenance cost per hour = 3.5% of price

Total variable cost (Tk h^{-1}) = (a + b + c + d) (7)

Total variable cost (Tk ha^{-1}) = (a + b + c + d)/Area covered in ha per h (8)

Harvesting cost with reaper

Harvesting cost with reaper was calculated by adding both the fixed cost and variable cost. The harvesting cost was calculated as follows:

C_{oc} (T) = Fixed cost +Variable cost (9)

where

C_{oc} (T) = harvesting cost, Tk ha^{-1}

Break-even analysis

The break-even analysis is a useful tool to study the relationship between operating costs and returns. It is the intersection point at which neither profit nor loss is occurred. A break-even point (BEP) defines when an investment will generate a positive return and can be determined graphically or with simple mathematics. The BEP analysis was done considering the actual cost of operation with the reapers and cost of manual harvesting using following formula(Hunt, 1995):

Break-even point, $$BEP = \frac{FC}{RC - VC} \quad (10)$$

where

BEP = breakeven point, ha yr^{-1}

FC = fixed cost, Tk. yr^{-1}

VC = variable cost, Tk. ha^{-1}

RC = Rental charge, Tk. ha^{-1}

Results and Discussion

Plant characteristics

Plant height, panicle height, plant density and soil moisture measured before harvesting operation to control operation speed and cutting height of the reaper are given in Table 2.

Table 2. Crop characteristics of experimental plots

Crop parameter	Korean reaper	China reaper	BRRI reaper	Manual harvesting
Soil moisture, %	21.7	22.3	23.0	23.3
Plant height, cm	118	119.7	121.7	125
Panicle height, cm	23.1	23.6	23.8	25.8
Number of hill m^{-2}	24	24	24	19
Number of tiller m^{-2}	337	305	305.7	208
Yield, t ha^{-1}	4.0	5.0	5.2	4.5

Note**:** Average data of three replications is presented in the above Table

Field capacity

Reaper performance was measured in terms of theoretical field capacity, actual field capacity and field efficiency of the reapers. The results showed that the theoretical field capacity of Korean self-propelled reaper, China self-propelled reaper and BRRI reaper was 0.33, 0.25 and 0.27 ha h^{-1}, respectively (Fig. 2). Due to forward speed of the reapers, cutting width, number of pass and theoretical field capacity vary from one reaper to another. The field capacity of the reapers increases with the increasing forward speed. The actual field capacity of the Korean self-propelled reaper, China self-propelled reaper and BRRI reaper was 0.18, 0.17 and 0.15 ha h^{-1}, respectively (Fig. 2). Zami *et al*. (2014) reported that the average field capacity of imported Chinese self-propelled reaper and BRRI developed reaper was 0.20 and 0.25 ha h^{-1}, respectively which is higher than studied reapers. It might be the causes of land size, crop type and density, operator skill, soil condition etc. Similar theoretical and actual field capacity of Korean and Vietnam self-propelled reaper was reported for paddy harvesting in Aman season which was 0.15 and 0.23 ha h^{-1}, respectively (Nipa, 2016). Alizadeh *et al*. (2007) found the effective field capacity of power tiller-operated reaper and manual harvesting using sickle as 0.17 and 0.01 ha h^{-1} respectively. Labor requirements also varied with the field capacity of the reaper. Labor requirements were calculated as 5.4, 5.5, 6.6 and 128 man-h/ha for KR, CR, BR and manual harvesting of paddy, respectively. The grain losses for manual and mechanical harvesting using KR, CR and BR were 1.40%, 1.66%, 1.50% and 1.45%, respectively. The actual field capacity of the reaper depends on operational speed, soil condition, crop condition, different losses of time and operator's skill. Cutting width was same for all three reapers but the effective width of cut varied from one to another due to operator's personal skill. The weight and length of

BRRI reaper was more than that of others. Because of more length of the BR, turning radius was more in the field during operation that takes more time to reset from one direction to the opposite direction of operation. As a result, the actual field capacity of BRRI reaper was less than that of the others.

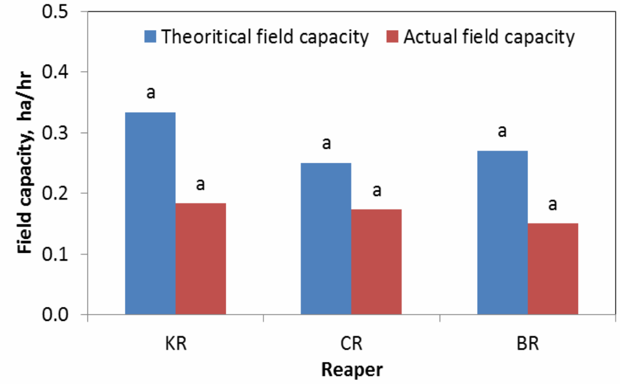

Fig. 2. Theoretical field capacity and actual field capacity of three different reapers (Bars with same letter do not differ significantly at $p > 0.05$)

Field efficiency

Field efficiency varied with wasted time, type and agronomic characteristics of a variety, plot size and operator's skill (Alizadeh and Allameh, 2013). Field efficiency of the KR, CR and BR was obtained 54.5%, 68% and 55.6%, respectively (Fig. 3). Field efficiency of CR was significantly higher ($p < 0.05$) compared to KR and BR due to time losses for turning and adjustment. However, field efficiency of KR and BR was found similar. Nipa (2016) reported that the field efficiency of Korean and Vietnam made self-propelled reapers was 50% and 64% for Aus and Aman harvesting season. Kalsirislip and Singh (1999) also reported that the field efficiency of a 3-m working width combine stripper is 74% for standing crop and 72% for lodged crop. Field efficiency of a whole-crop rice combine harvester was 72% for a common rice variety in Malaysia (Roy *et al.*, 2001). Based on the field demonstrations conducted during kharif 2002, 2003, 2004 and rabi/summer, 2004-05, the field efficiency of the power-operated reaper is 73% at an average operating speed of 3.2 km h^{-1}(Manjunatha *et al.*, 2009).

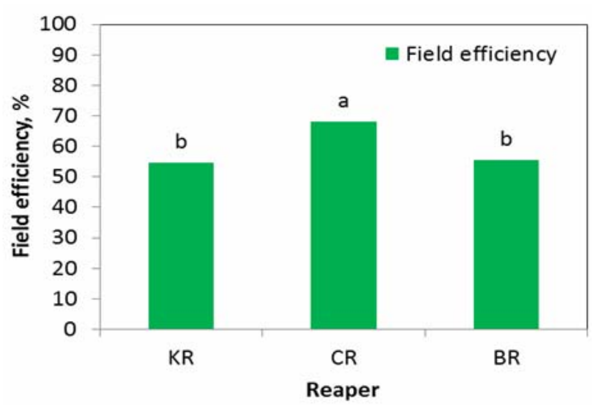

Fig. 3. Field efficiency of different types of reaper (Bars with same letters do not differ significantly whereas bars with dissimilar letters differ significantly at $p < 0.05$.

Harvesting losses

Pre-harvest losses of the studied plots were similar. Post-harvest losses varied significantly with the mode and types of harvesting. Harvesting loss of KR was found significantly higher (1.66%) compared to CR (1.50%), BR (1.45%) and manual (1.40%) harvesting method (Fig. 4). It occurred for high number of unreaped plant population due to high forward speed of reaper during operation. Alizadeh and Allameh (2013) obtained similar result (1.54%) for paddy harvesting by power-operated reaper. Baneh *et al.* (2012) observed lower harvesting loss of power-operated reaper (0.84%) compared to manual harvesting (1.015%). Harvesting loss might vary with the operator's skill, harvesting time, soil condition and agronomic characteristics of the paddy. The header conveying and total machine losses of the self-propelled walking type vertical conveyor reaper were found 0.85% and 3.95%, respectively when harvested the crops at higher moisture content than normal limit of 23–27% (Kurhekar and Patil, 2011). They also mentioned that early harvesting reduced pre-harvest and shattering loss in operation, on the other hand delayed harvesting caused more loss due to low moisture content.

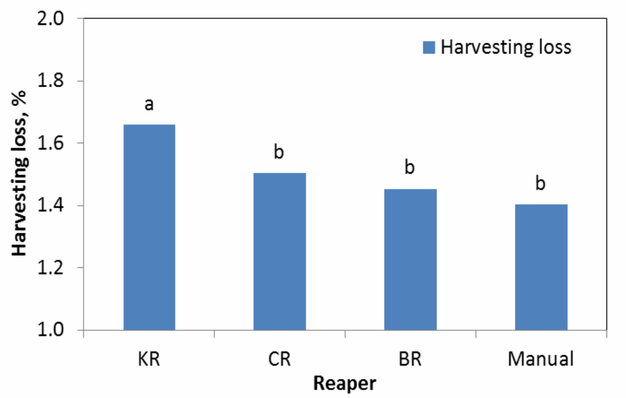

Fig. 4. Harvesting loss in different method (Bars with same letters do not differ significantly whereas bars with dissimilar letters differ significantly at $p < 0.05$)

Fuel consumption

Fuel consumption of the reapers was obtained 0.76, 0.48 and 1.25 l h^{-1}or 4.11, 2.61 and 8.39 l ha^{-1} for KR, CR and BR, respectively (Table 3). Fuel consumption of the reaper varies from one to another due to engine power, crop density and operator's skill. In BRRI reaper, fuel consumption was more compared to the others because of more turning time and high engine power.

Table 3. Operational time, fuel consumption and cost of operation of the studied reapers

Parameter	Korean reaper	China reaper	BRRI reaper	Manual harvesting
Time of operation, min	11.06	10.09	12.19	135
Turning loss time, min	3.76	1.4	4.07	-
Turning loss, %	34.33	14.03	33.86	-
Fuel consumption, l h^{-1}	0.76	0.48	1.25	-
Fuel consumption, l ha^{-1}	4.11	2.61	8.39	
Cost of operation, Tk ha^{-1}	852	611	1097	4750

Crop delivery

Crop delivery rate were measured during harvesting operation (Table 4). Korean reaper delivered the highest number of plant population compared to the others. Crop delivery rate depends on plant population per unit area, effective cutting width, forward speed and conveyor belt speed of the reaper. There is an inter-relationship between forward speed and conveyor belt's speed of a reaper. If forward speed increases and conveyor belt's speed decreases, then plant population becomes matted or clot or rate of uncut population increases.

Table 4. Crop delivery rate of the three reapers as affected by width of cut, forward speed and plant density

Reaper	Width of cut, m	Forward speed, km h^{-1}	Plant density, no. m^{-2}	Crop delivery, no. of plants s^{-1}
Korean reaper	1.2	2.78	337	312.3
China reaper	1.2	1.95	305	218.5
BRRI reaper	1.2	2.28	305.66	256.5

Break-even analysis of different types of reaper

Results of break-even points of different reapers are shown Fig. 5. The cost of crop harvesting (without binding and threshing) was Tk. 852, Tk. 611 and Tk. 1097 per ha for KR, CR and BR, respectively and Tk. 4750 per ha of manual harvesting. The break-even point of the reapers is 9.15, 7.82 and 8.43 ha yr^{-1} for KR, CR and BR, respectively. It shows that the harvesting cost of reaper decreases with the increase in annual land use coverage. At break-even point, the cost of mechanical and manual harvesting would be same. The breakeven point (ha yr^{-1}) of the KR, CR and BR were found 9.15, 7.82 and 8.43 based on 400 hours usages of the reaper per year. It means that the reapers will be economical to the farmers when the annual use exceeds above amount of land. A comparison of the reapers from the view points of operator is presented in Table 5.

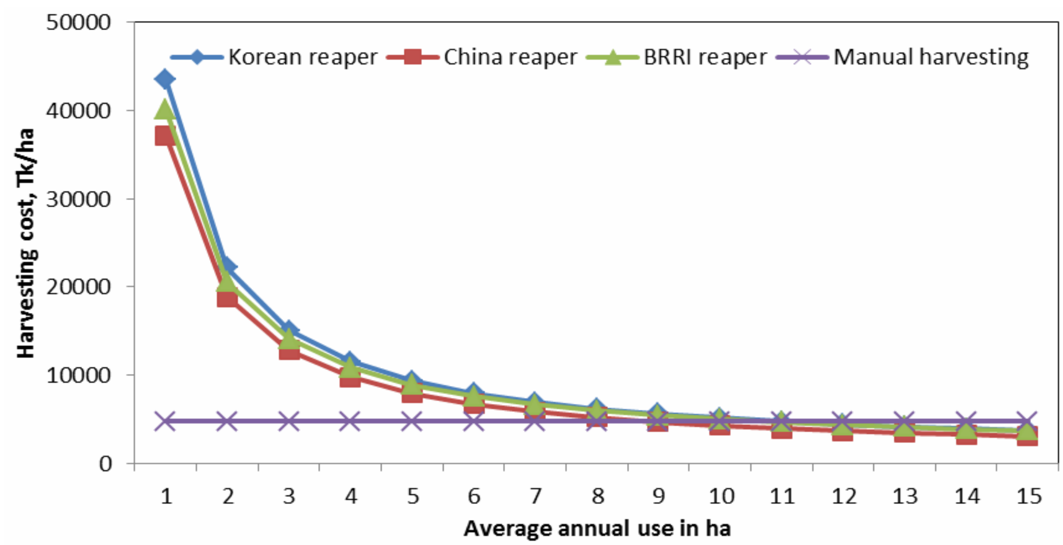

Fig. 5. Break-even points of different types of reaper

Table 5. A comparison of the reapers from the view points of operator

Name of machine	Comparative advantages	Comparative disadvantages
Self-propelled Korean reaper	Less turning radius Light weight Less vibration Smooth discharge	More un-cut crops Laborious
Self-propelled China reaper	Less turning radius Light weight Less vibration Smooth discharge No un-cut crops	Laborious Needs more downward pressure
BRRI reaper	Riding facility Less laborious Multi-purpose use of PT Less prices	More vibration More turning radius Rough discharge More weight

Conclusions

Paddy harvesting is one of the labor intensive and tedious works of rice production. Three studied reaper was found suitable for harvesting Aman paddy in Bangladesh condition. Mechanical harvesting was found beneficial in terms of field capacity, cost of harvesting and human drudgery compared to manual harvesting. Actual field capacity and field efficiency increased with the increase of land size and operator's skill. It is evident that the reapers could be used successfully for post-harvest operation in Bangladesh with labor saving and elimination of human drudgery problems.

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