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


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 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/
Performance evaluation of power operated reaper

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 were T1 = Self-propelled Korean reaper (KR), T2 = China reaper (CR) and T3 = 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

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

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 x 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 m² 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):

\[
\text{Theoretical field capacity (Ct)} = \frac{W \times S}{10}
\]

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):

\[
\text{Actual field capacity (Ca)} = \frac{Ta}{Tt}
\]

where

- \(Ca\) = 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):

\[
\text{Field efficiency (Fe)} = \frac{Ca \times 100}{Ct}
\]

where

- \(Ct\) = Theoretical field capacity in ha h\(^{-1}\)
- \(Ca\) = Actual 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):

\[
\text{Harvesting loss (HL)} = \frac{W_{hl} - W_{phl} \times 100}{Y}
\]

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,

\[
D = \frac{(P - S)}{L}
\]

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:

\[
\text{Interest on investment, } I = \frac{(P + S)}{2} \times i
\]

where

- \(P\) = purchase price of dryer, Tk
- \(S\) = salvage value, Tk
- \(i\) = interest rate, %
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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:

\[ C_{hc}(T) = \text{Fixed cost} + \text{Variable cost} \] (9)

Table 2. Crop characteristics of experimental plots

<table>
<thead>
<tr>
<th>Crop parameter</th>
<th>Korean reaper</th>
<th>China reaper</th>
<th>BRRI reaper</th>
<th>Manual harvesting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil moisture, %</td>
<td>21.7</td>
<td>22.3</td>
<td>23.0</td>
<td>23.3</td>
</tr>
<tr>
<td>Plant height, cm</td>
<td>118</td>
<td>119.7</td>
<td>121.7</td>
<td>125</td>
</tr>
<tr>
<td>Panicle height, cm</td>
<td>23.1</td>
<td>23.6</td>
<td>23.8</td>
<td>25.8</td>
</tr>
<tr>
<td>Number of hill m²</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>19</td>
</tr>
<tr>
<td>Number of tiller m²</td>
<td>337</td>
<td>305</td>
<td>305.7</td>
<td>208</td>
</tr>
<tr>
<td>Yield, t ha⁻¹</td>
<td>4.0</td>
<td>5.0</td>
<td>5.2</td>
<td>4.5</td>
</tr>
</tbody>
</table>

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.

**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).

**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.

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

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

![Fig. 3. Field efficiency of different types of reaper](image-url) (Bars with same letters do not differ significantly whereas bars with dissimilar letters differ significantly at $p < 0.05$)
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

<table>
<thead>
<tr>
<th>Reaper</th>
<th>Width of cut, m</th>
<th>Forward speed, km h⁻¹</th>
<th>Plant density, no. m⁻²</th>
<th>Crop delivery, no. of plants s⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Korean reaper</td>
<td>1.2</td>
<td>2.78</td>
<td>337</td>
<td>312.3</td>
</tr>
<tr>
<td>China reaper</td>
<td>1.2</td>
<td>1.95</td>
<td>305</td>
<td>218.5</td>
</tr>
<tr>
<td>BRRI reaper</td>
<td>1.2</td>
<td>2.28</td>
<td>305.66</td>
<td>256.5</td>
</tr>
</tbody>
</table>

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 viewpoint of operators

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

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.

References


