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An ASABE Meeting Presentation

DOI: https://doi.org/10.13031/aim.202000785

Paper Number:2000785

Sustainable Paddy Harvesting Solution for the Southern Delta of Bangladesh

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Written for presentation at the
2020 ASABE Annual International Meeting
Sponsored by ASABE
Omaha, Nebraska
July 12–15, 2020

ABSTRACT

Southern Delta of Bangladesh is lagging behind in adoption of agricultural machinery due to its agro-ecological characteristics in contrast with the rest of the country. Agriculture in this region is characterized by low productivity due to salinity, water logging, limiteduse of modern technologies, inadequate control over water resources and repeated crop losses due to natural calamities like cyclone, tidal surge, flood, etc. Harvesting is one of the areas that need machinery intervention for reduction of cost, time and losses. Three types of harvesting machines namely reaper, mini-combine and small to medium size combine harvesters are available options for paddy harvesting in Bangladesh. The main objective of the study was to identify appropriate paddy harvesting machines forsouthern delta of Bangladesh. The experiments were conducted to evaluate the technical and economic performances of reaper (Model: Vikyno AR 120), mini combine harvester (Model: 4LBZ-110) and combine harvester (Model-AG600GA) in compared to manual harvesting of paddy. The result shows that effective field capacity of the combine harvester was 0.45 ha/h in comparison to reaper (0.22 ha/h) and mini-combine harvester (0.09 ha/h). Cost savings of combine harvester was 61% over manual harvesting compared to reaper (45%) and mini-combine harvester (51%). Similarly, combine harvester saves 70% labor over manual harvesting. The estimated BCR (Benefit Cost Ratio) and pay-back period of combine harvester were 1.62 and 2.08 year, respectively. The average total harvesting loss of combine harvester was found 1.62% which was significantly less than manual harvesting (6.36%). In addition to this, harvesting of 100% shattered paddy, even in water logged and wet conditions are possible by combine harvester. But, reaper and mini-combine harvester cannot harvest paddy in such conditions. Due to climate prone vulnerability, it is also necessary to harvest large area of paddy within short time. Therefore, combine harvester would be an appropriate option for harvesting paddy in southern delta of Bangladesh. Based on these findings, the government of Bangladesh comes up with a program to popularize three thousand units small to medium size combine harvester and two thousands units of reaper with 60% subsidy in the country by 2020-21 fiscal year.

Keywords:*Paddy, Combine harvester, Mini-combine, Reaper, Cyclone prone area, Benefit.*

1. Introduction

Paddy is a major cereal crop in Bangladeshwhich contributes significantly to national food security and socio-economic development. Timely harvesting of paddy is very important to reduce postharvest losses. Due to unavailability of mechanical harvesting system, significant amount of field losses of paddy havebeen occurreddue to natural calamities and shortage of time during harvesting period (Noby et al. 2018). Now a day, timelyharvesting of paddy is a big challenge due to shortage of labor and high wage of labor during harvesting season. Yet, evidence indicates 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 (Zhang et al., 2014). Projections also indicate that rice and wheat production will need to increase by 0.4 and 2.17% per year, to keep pace with the additional two million population added annually (Mainuddin and Kirby, 2015). However, the two conditions cannot be fulfilled due to shortage of manpower at that particular time. At the same time, there is little scope to extend the agricultural land frontier; crop land availability in Bangladesh has declined by 68,760 ha year^{-1} (0.73%) since 1976 (Hasan et al., 2013). In other words, Bangladesh needs to produce more food from the same land by reducing farm production cost though mechanization. Introduction of appropriate machinery is one of the major factors for reducing time and labor requirements, production cost and also to help fitting another crop in between successive two crops (Zami et al., 2014). Another important opportunity will be created for the unemployed people in the field operation of harvesting machinery and its maintenance atengineering workshops. Miah et al. (2002) showed that farm mechanization has remarkable positive impacts in creating employment opportunities, higher income, increasing household assets and increasing the overall standard of living of rural laborers in Bangladesh.

Generally, 3 types of harvesting machines like reaper, mini-combine and combine harvester are available worldwide. In addition to these, many developing countries like Bangladesh are using manual harvesting widely due to unavailable of modern technologies. In assessing technical and economical performances of any harvesting machine, the factor which greatly influences is the area covered by the machinein unit time. According to the manufacturers' specifications of combine harvester, the area coverage per unit time is higher than that of reaper, mini-combine and manual harvesting. Combine harvesters are one of the most economically important labor saving inventions, significantly reducing the fraction of the population engaged in agriculture (Constable*et al*.,2003)**.** The modern combine harvester, or simply combine, is a versatile machine designed to efficiently harvest a variety of grain crops. ACI Motors Limited, Bangladesh, has recently imported a Yanmar combine harvester (Model-AG600GA) for paddy harvesting in Bangladesh. Before using the combine harvester at farmers' level, it is necessary to assessthe technical and economical performances of the combine. Under this situation, the objectives of the study were to evaluate the technical and economic performances of theharvesters (combine, mini-combine and reaper)and comparing their performancesalong withmanual harvesting system.

2. Methodology

2.1 Study location

The performance study of the selected mechanical harvesters for harvesting of paddy were conducted at *Basail*, *upazila* of Tangail district and *Wazirpur, upazila* of Barisal district in Bangladesh as shown in Figure 1.Three paddy plots for each harvester were used and harvested during *Boro*-2019 (April-May 2019).

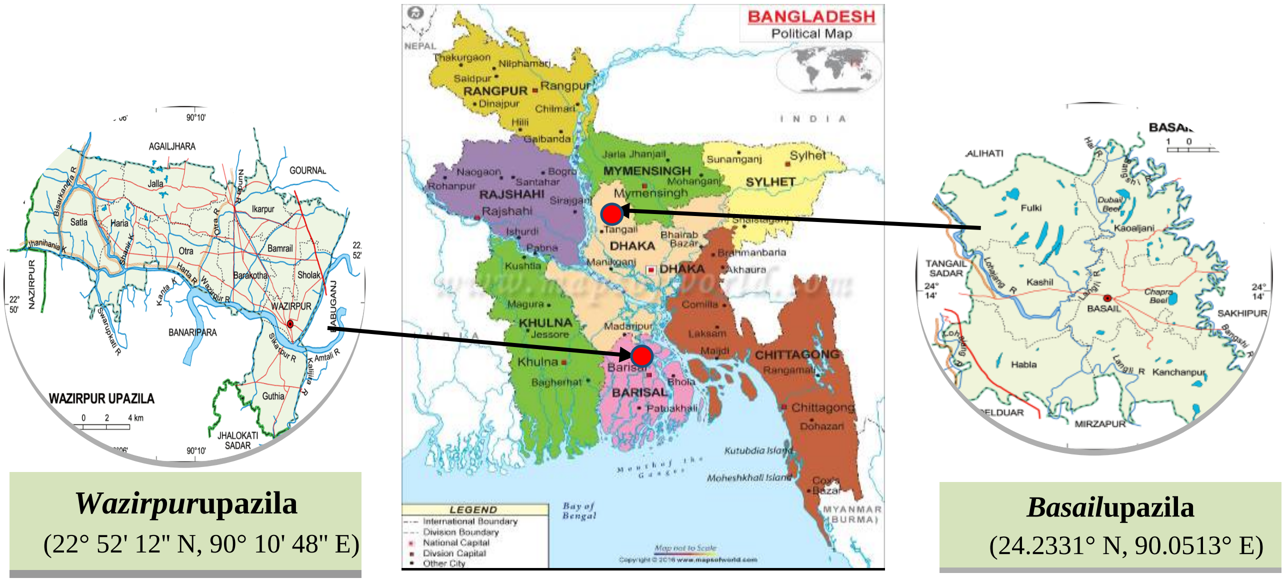

Figure 1.Study locations in Bangladesh map

2.2 Selected combine harvester

Mechanical paddy harvesting wasconducted by using three harvesters, i) combine harvester (Model: AG600GA), ii) mini-combine harvester (Model: 4LBZ-110) and iii) reaper Model: (Vikyno AR 120). Pictorial views of selected harvestersare shown in Figure 2 and technical specifications are presented in Table 1.

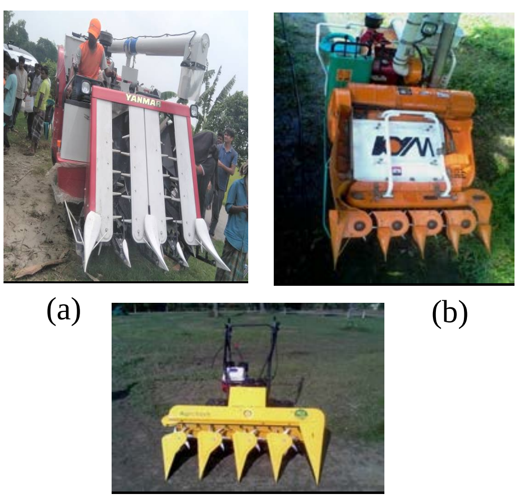

Figure 2. Pictorial views of harvesters: a) combine, b) mini combine and c) reaper

Table 1.Specifications of combine harvester

Testing Item	Designed Value		
	Combine	*Mini combine*	*Reaper*
Model	AG600GA	4LBZ-110	AR 120
Dimension (L×W×H) m^3	4.3×1.9×2.4	2.6×1.3×2.0	2×1.4×1.1
Weight (kg)	3117	950	126
Reaping width (m)	1.4	1.09	1.2
Forward Speed (km/h)	0~7.38	1.6~2.8	3.6
Fuel consumption (L/h)	08~12	1.0-1.5	0.8-1.0
Engine Power (hp)	70	20	6.5
Engine type	Diesel	Diesel	Petrol
Engine Speed (rpm)	2500	2200	1800
Working Efficiency (ha/h)	0.25-0.50	0.07-0.13	0.20-0.30
Country of origin	Japan	China	Vietnum
Importer in Bangladesh	ACI Motors	Glory Engg	ACI Motors

2.3 Paddy harvesting bymechanical harvester

For the performance evaluation of threeselected harvesters, total 9 plots of paddy were selected and harvested by the harvesters. All activities ofperformance evaluation were done very carefully. During paddy harvesting, all activities of combine and mini-combine harvesters(harvesting to cleaning tasks) were performed in a single operation but in case of reaper, threshing was done bya power thresher.

2.4 Performance indicating parameters

To evaluate technical and economic performances of harvestersand tocompare their performancesalong with each manual harvesting system, the following performance indicators were considered: (i) operation time, (ii) labor requirement for harvesting, (iii) fuel consumption, (iv) field capacity, (v) working speed, (vi) effective harvesting time and (vii) grain losses.

2.5 Field capacity

For evaluation of field capacity, the following data were taken during paddy harvesting operation: (i) area of the plot; (ii) forward speed of the machine; (iii) cutting width of the machine; (iv) time required to harvest the specified area; (v) time loss due to refueling, cleaning, machine adjustments, minor repair and turning of the machine.

2.6 Forward speed

Forward speed was measured by dividing the distance by time required to travel the machine of that distance. Same procedure was considered six times in each plot for determining average forward speed. The following equation was used to determine the forward speed of combine harvester (Hunt, 2001).

$$\text{Forward speed (km/hr)},\ S = \frac{3.6D}{t} \quad \text{(i)}$$

where, D = distance (m) and t = time (s).

2.7 Effective field capacity

The effective field capacity is the actual average rate of coverage by the harvester, based upon the total field time. The area covered divided by the total time is the effective field capacity. The effective field capacity was determined from measuring all the time elements involved while harvesting (Hunt, 2001).

$$\text{Effective field capacity (ha/hr)},\ C_{eff} = \frac{A}{T} \quad \text{(ii)}$$

where,T = total time for reaping operation (hr) and A = area of land reaping at specified time.

2.8 Fuel consumption

Before starting the harvesting operation, the fuel tank of the combine harvester was filled up and at the end of the harvesting operation of each plot the required fuel to fill the tank was determined by using measuring flask. For determining fuel consumption per unit area, following equation was used (Hunt, 2001).

$$\text{Fuel consumption (L/ha)},\ F = F_a/A \quad \text{(iii)}$$

where, F_a = fuel used during operation (L) and A= area of operation, (ha).

2.9 Determination of mechanical harvesting losses

In general, there are four types of losses were considered to use a harvester. These are i) shatter loss, ii) cutter bar loss, iii) cylinder loss and iv) separating loss. In the experiment following procedures were considered for mechanical harvesting losses measurement.

i) Shatter loss

Shatter losses in direct combining include heads, pods or ears, and free grain lost during cutting and conveying operations. The following equation was used to determine the shatter loss (Hunt, 2001).

$$\text{Shatter loss, kg/ha} = \frac{\text{Avg. weight of droped grain on the ground during cutting \& conveying, kg}}{\text{Area covered, ha}} \quad \text{(iv)}$$

ii) Cutter bar loss

Cutter bar loss indicates grains those are lost due to rough handling by the cutter bar. Following equation was used to determine cutter bar loss (Hunt, 2001).

$$\text{Cutter loss, kg/ha} = \frac{\text{Avg. weight of grain lost due to rough handling of cutter bar, kg}}{\text{Area covered, ha}} \ldots\ldots\ldots\ldots\ldots\ldots\text{(v)}$$

iii) Cylinder loss

Grains lost out the rear of the combine in the form of threshed heads indicate cylinder loss. Following equation was used to determine cylinder loss (Hunt, 2001).

$$\text{Cylinder loss, kg/ha} = \frac{\text{Avg. weight of unthreshed heads lost out the rear of combine, kg}}{\text{Area covered, ha}} \ldots\ldots\ldots\ldots\ldots\text{(vi)}$$

iv) Separating loss

Separating loss means the grains lost out the rear of the combine in the form of threshed grain. The following equation was used to determine separating loss (Hunt, 2001).

$$\text{Separating loss, kg/ha} = \frac{\text{Avg. weight of threshed heads lost out the rear of combine, kg}}{\text{Area covered, ha}} \ldots\ldots\ldots\ldots\text{(vii)}$$

2.10Grain weight measurement

After manual and mechanical harvesting of paddy, two types of grain were collected from the field; i.e., one from small area for grain yield measurement and another for grain loss measurement. Both types of grain were collected in polythene bag and weighted by using a digital balance in the field and in a lab. In both cases, grain weighted after reducing the grain moisture in a certain level through sun drying or natural drying in lab.

2.11 Benefits of mechanical harvesting

The costs of two different harvesting methods, i.e., mechanical and manual harvesting were compared to determine the benefits of mechanical harvesting. The following equations were used to determine cost, saving and percent of cost saving.

i) Total manual harvesting cost (BDT/ha) = Wages of labor (BDT/man) × No. of labor (man/ha) ....(viii)

ii) Cost saving for using combine harvester (BDT /ha) = Cost of manual harvesting (BDT /ha) – Cost of mechanical harvesting using a harvester (BDT/ha)...(ix)

$$\text{iii)Cost saving, (\%)} = \frac{\text{Manual harvesting cost (BDT/ha) - Mechanical harvesting cost (BDT/ha)}}{\text{Manual harvesting cost (BDT/ha)}} \times 100\text{...(x)}$$

2.12Benefit-cost ratio (BCR) and payback period (PP)

Benefit-cost ratio (BCR) and payback period (PP) were estimated by using the following formula (Gittinger, 1982)**:**

BCR = ∑ Present worth of Benefits (PWB)/ ∑ Present worth of costs (PWC) ……………….…..(xi)

Payback period = Investment (total initial, BDT)/ Net benefit (BDT/yr)……….……….………….(xii)

3. Results and Discussion

3.1 Technical performance of selected combine harvester

Field experiment data of combine, mini combine and reaper at the selected experimental locations were collected during *Boro*/2019.Average values along with standard deviations of forward speed, fuel consumption, effective field capacity and field efficiency were determined andpresented in Table 2. The estimated field performances were varied due to variation of harvester type, plot size, forward speed, operator's skill and soil condition.

Table 2**.**Technical performance of combine, mini combine and reaper

Machine	Avg. forward speed(km/h)	Avg. fuel consumption (L/ha)	Avg. effective field capacity(ha/h)	Avg. field efficiency (%)
Combine harvester (Model-AG600GA)	6.09±0.05	21.49±0.06	0.4545±0.0031	53.32±1.28
Mini-combine (Model: 4LBZ-110)	1.61±0.03	19.52±0.04	0.0912±0.0024	54.16±2.11
Reaper (Model: AR 120)	3.16±0.06	3.29±0.07	0.2214±0.0032	57.78±2.18

3.2 Comparison of technical performances of combine with mini combine and reaper

To know the better options for harvesting, the performance indicators of combine, mini combine harvester and reaper were carried out and presented in Table 2. Identifications of usable conditions of combine, mini-combine harvesters and reaper are also necessary to know for providing information to farmers and extensions service holders. Average effective field capacity of the combine harvester (Model-AG600GA) was found 0.45 ha/h which is higher than that of mini-combine harvester (Model: 4LBZ-110) 0.09 ha/h and reaper (Model: AR 120)0.22 ha/h. Due to higher field capacity in comparison to mini-combine harvester, reaper and manual harvesting system, combine harvester will definitely be appropriate to harvest large area within short time. In addition to this, 100% shatteredcrops are possible to harvest using the combine harvester which is not possible by mini-combine harvester and reaper. Southern region of Bangladesh is vulnerable area. Shuttering of paddy on the field at the matured stage is common phenomena in the region. Due to climate vulnerability, it is also necessary to harvest large area of paddy within a short time. All thementioned issues are possible to resolve by using a combine harvester. However, farmers in some areas also preferred to have rice straw intact after harvesting and threshing, in that situation reapers also have valid ground to be promoted in the country.

3.3 Economic performance of harvesters over manual harvesting

To ascertainthe benefits of mechanical harvesting over manual harvesting, necessary performance analysis were carried out for the threeselected harvesters as shown in Table 3. The results supported that investment on a mechanical harvester is highly profitable. Costs saved during mechanical harvesting over manual harvesting were found 61%,51% and 45%, respectively by using a combine harvester, mini-combine harvester and reaper.

Table 3**.**Different financial features of combine harvester operation

Item	Unit*	Amount		
		Combine	Mini combine	Reaper
Purchase price of combine (P)	BDT	2800,000	650,000	165,000
Working life (L)	yr	10	10	5
Fixed cost per hectare	BDT/ha	2,789	3,270	593
Variable cost per hectare	BDT/ha	6,732	8,687	12,857
Operating cost per hectare	BDT/ha	9,521	11,957	13,451
Manual harvesting cost	BDT/ha	24,400	24,400	24,400
Cost saved	%	61	51	45

3.4 Benefit cost ratio (BCR) and payback period (PP)

Economic analysis was carried out from the viewpoint of harvester owner. Discounted measures of project were used for financial analysis since undiscounted measures of project worth is quite unable to be taken account of the timing of benefits and costs. The estimated results showthat investment on a mechanical harvester is profitable. The results in Table 4 show that the payback period (PP) of harvesters were determined as 2.08, 2.42, and 0.46 year, respectively for combine harvester, mini-combine harvester and reaper. The estimated BCR for a combine harvester, mini-combine harvester and reaper is 1.62, 1.46 and 1.40, respectivelythat are higher than unity. It indicates that investing on a mechanical harvester is highly profitable.

Table 4. Different financial features of harvester operation business

Item	Unit*	Amount		
		Combine (Model-AG600GA)	Mini combine (Model: 4LBZ-110)	Reaper (Model: AR 120)
Operating cost of harvester	BDT/ha	9521	11,957	13,451
Return from rent out charge	BDT/ha	16,000	16000	16000
Benefit-cost ratio (BCR)	-	1.62	1.46	1.40
Payback period (PP)	yr	2.08	2.42	0.46

** BDT: Bangladeshi Taka (Approximately 84 BDT = 1 US $), Average effective field capacity = 0.45 ha/h, Average daily working hour = 8h; Yearly use = 40 days, Price of diesel=65 BDT/litre.*

3.4 Manual paddy harvesting cost

Manual paddy harvesting cost was estimated considering the paddy harvesting to cleaning, all operations were conducted manually. Average cost of manual reaping, straw binding and carry to home, threshing and cleaning of paddy were estimated as presented in Table 5. Costing was calculated considering the necessary manual labor requirement in man-day per hectare. The necessary man-day/ha were 23, 15, 15 and 8, respectively for paddy reaping, straw binding and carry to home, threshing and cleaning. Total manual labor requirement inman-day/ha was 61 and manual harvesting to cleaning cost was found BDT 24400 perha.

Table 5**.**Manual paddy harvesting cost

Type of work	No of man-day/ha	BDT/man-day	Total cost, BDT/ha
Paddy reaping	23	400	9200
Straw binding & carry to home	15	400	6000
Paddy threshing	15	400	6000
Paddy cleaning	8	400	3200
Total manual paddy harvesting cost			**24400**

3.5 Grain loss saved by mechanical harvesters

Grain loss saved for using the harvesters over manual harvesting system were estimated andpresented in Table 6. Grain loss could be saved 4.74%, 5.12% and 2.14%, respectively for using a combine, mini-combine and reaper over manual harvesting. Grain loss might vary with the operator’s skill, soil condition, harvesting time and agronomic characteristics of the paddy.

Table 6. Grain loss saved bymechanical harvesting over manual harvesting of paddy

Harvesting method	Total loss, % (From harvesting to cleaning operation)	Loss saved, %
Manual harvesting	6.36	
Reaper (Model: AR 120)	4.22	2.14
Mini-combine (Model: 4LBZ-110)	1.24	5.12
Combine harvester (Model-AG600GA)	1.62	4.74

3.7 Labor saved over manual harvesting

The net labor requirements from harvesting to cleaning operations for the both harvesting methods (mechanical and manual) were determined and presented in Table 7. Total labor requirements were found 18 man-day/ha, 21 man-day/ha, 29 man-day/ha and 61 man-day/ha for combine, mini-combine, reaper and manual harvesting system, respectively. In comparison to manual harvesting, mechanical harvesting resulted in savings of 70%, 65% and 52%, respectively for combine, mini-combine and reaper for paddy harvesting.

Table 7. Labor saved using mechanical harvesting over manual harvesting

Item	Labor involvement (man-day/ha)			
	Combine	**Mini combine**	**Reaper**	**Manual**
Paddy harvesting	2	5	1	23
Paddy bags carry from field to home	8	8		-
Threshed straw binding and carrying to home	8	8		-
Straw with paddy carrying from field to home	-		15	15
Threshing bypower thresher			5	
Manual threshing	-			15
Cleaning	-		8	8
Total labor (from harvesting to cleaning)	**18**	**21**	**29**	**61**
Labor saved over manual harvesting (%)	**70**	**65**	**52**	

4. Conclusions

Technical and financial performance indicating parameters of the harvesters were determined carefully and all financial parameters were compared with manual harvesting system. Results revealed that all three selected mechanical harvestersare time, labor and cost saving advantages over manual harvesting along with further advantages of reduction ofharvesting losses, human drudgery and increased crop productivity. Notable advantages are identified in favor of combine harvester over other means of harvesting of paddy and found suitable for Bangladesh condition.However, farmers in some areas also preferred to have rice straw intact after harvesting and threshing, in that situation reapers also have valid ground to be promoted in the country. The adoption of mechanical harvesting in the country would increase to availability of rice by reducing the losses and increasing productivitythat will contribute significantly in the food security and the development of livelihoods of rural community of Bangladesh. Based on these findings, the government of Bangladesh comes up with a program to popularize three thousand units small to medium size combine harvester and two thousands units of reaper with 60% subsidy in the country by 2020-21 fiscal year.

Acknowledgement

This article as part of Appropriate Scale Mechanization Consortium (ASMC) project "Appropriate Scale Mechanization Innovation Hub (ASMIH) - Bangladesh" is made possible by the support of the American People provided to the Feed the Future Innovation Lab for Sustainable Intensification through the United States Agency for International Development (USAID) and University of Illinois at Urbana-Champaign, USA (Sub award Number: 2015 -06391 -06, Grant code: AB078). The contents are the sole responsibility of the authors and do not necessarily reflect the views of USAID or the United States Government. Authors would like to acknowledge The ACI Motors Ltd. for providing the combine harvester to conduct the research work.

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