Irish Interdisciplinary Journal of Science & Research (IIJSR)
Volume 9, Issue 3, Pages 14-25, July-September 2025

On-Farm Evaluation and Verification of Engine Driven Harvester

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DOI: Under Assignment

Article Received: 07 May 2025 *Article Accepted: 19 July 2025* *Article Published: 27 July 2025*

ABSTRACT

In Ethiopia harvesting of cereal crops is one of the major attentive agricultural operations in agriculture production, which demands considerable amount of Labours. The availability and cost of labour during wheat crop harvesting season are serious problems. It is therefore, essential to adopt appropriate harvesting machinery is urgently needed to reduce labor and production costs so that the timeliness in harvesting operation could be ensured and field losses are minimized to increase production on the farm. In this study, performance of walking behind reaper used for wheat harvesting was assessed and compared with manual harvesting using sickle. The objective of this study was to evaluate the field performance of walking behind reaper at farmer's field. The results showed that the actual field capacity of the reaper was found as 0.072 ha/h with a field efficiency of 66.90% per cent at an average operating speed of 2.15 km/h. The fuel consumption was observed as 1.09 l/h. The harvesting cost of reaper was 46.93% less as compared with manual harvesting. The overall performance of power reaper for wheat harvesting was found satisfactory.

Keywords: Actual Field Capacity; Field Efficiency; Harvesting Cost; Labour; Machinery; Performance; Production; Reaper; Timeliness; Wheat.

1. Introduction

As Ethiopia is primarily an agrarian country, agriculture and farm production play an important role. Wheat is one of the major crops and staple food being produced in the world. Harvesting of crops is an important field operation. Harvesting operation includes cutting, laying, gathering, transporting, stacking the cut crop. In Ethiopia harvesting methods being used are manual harvesting and mechanical harvesting.

Production of wheat is increasing but in most of the parts of the country the harvesting of wheat crop is still being done manually. Harvesting of crop is one of the most labour intensive operations in agriculture. Manual harvesting requires about 25% of the total labour requirement of the crop production (Murumkar, 2014). Depending upon the crop density, 125man-hr required for cutting of one ha of wheat field by using traditional sickle (Ashebir, 2020). It is estimated that harvesting and threshing consumes about one third of the total labour requirement of complete crop production system (Anurag *et al.*, 2018). Labour scarcity during peak period of harvesting leads to delay in harvesting and causes grain loss. Also high labour cost during peak period adds extra cost in total cost of cultivation.

The small scale farmers of cannot afford to buy a combine harvester due to high initial investment. Using of a small machine is suitable for small field because of low technical experience for operation and maintenance and low capital requirements (El-Sharabasy, 2006). Walking type vertical conveyer reaper, power tiller and tractor front mounted reaper save 50-60%labor and harvesting cost by 60-70% as compared to manual harvesting (Metwalli et al., 1995). On the other hand reapers are other alternative harvesting equipment's provided straw is considered as economic by-product for animal feed (Singh, 2002).

Reapers are appropriate for small farm holding farmers and it is essential to introduce these machines for small farm holding farmers as an alternative. Laukik *et al.* (2014) reported that the harvesting cost using a compact harvester is considerably low as compared to manual harvesting. Hence, keeping these facts in view, the study was conducted to evaluate and verify walking behind engine operated reaper in farmer's field condition.

1.1. Study Objective

To Evaluate and Verify Engine Driven Harvester.

2. Materials and Methods

2.1. Materials

The materials or equipment's were used for the field experiment listed in the following table.

Table 1. List of equipment's used

S. No.	Equipment	Description of Use
1	Data sheet	Used to record the data
2	Digital timer	Used to record the time
3	Graduated cylinder	Used to measuring the fuel consumption
4	Tag and metal frame	To identify the grain loss before and after harvest
5	Poly bag (sample bag)	Used for grain collection
6	Measuring Tape	Used for measuring length
7	Canvas sheet (2m * 1m)	Used to collect conveying loss
8	Digital balance	Used for measuring length
9	Labeling tag	Used for marking the area

2.2. Methods

This section deals with the procedures adopted to evaluate the performance of walking behind engine operated reaper. Field experiment was carried out at farmer's wheat field at Hetosa district of Arsi zone. This is carried out to obtain actual data on machine performance, operating accuracy, work quality and adaptability to desired crops and field conditions.

2.2.1. Description of the reaper

The walking behind reaper mainly consists of a cutter bar, header, conveyor unit, power unit, transmission system, frame and wheels. The header carries the cutter bar and the driven-shaft of the conveyor unit. When the reaper started to walk through the wheat field, the cutter bar reaps the straw using slider crank mechanism to reciprocate sets of knives moving between ledgers; the reaped straw falls on the ground.

2.2.2. Working principle

The reaper is walking behind type of reaper which is powered by the petrol engine. The engine power is transmitted to cutter with the combination of V-belt and chain-sprocket mechanism. Reciprocating cutter blade slides over fixed blade and creates scissoring action responsible for cutting the crops. After cutting, the cut crop is conveyed with the help of star wheel at one side by the lugged belt conveyer for easy collection and bundling.

2.2.3. Performance evaluation of the reaper

The performance data were categorized as data for test conditions and data for machine performance measures. The data for test conditions included, crop parameters, condition of the field, and condition of the machine and operator. Performance of the machine includes the operational speed, field capacity (ha/h), percentage of grain losses, fuel consumption per hour (L/h) and man-hours required of machine harvesting and conventional method which was harvesting by sickle. The field performance evaluations of the machine were conducted as per FAO test standards (FAO, 1994).

2.2.3.1. Crop parameters determination

Condition of the crop include crop kind, crop variety, susceptibility to shattering, ripening stage, plant density, lodging angle of the crop plant, moisture content of the stem and the grain at the time of harvesting as well as potential yields per hectare. The crop conditions have influence on the performance of harvesting machine. For determining the plant height in the test field, the heights of plants from ground to the upper part of the panicle were measured. For determining the plant populations of the harvested wheat crops were counted within 1 m^2 square frame. The number of plants from these areas gave plant population per meter square. The height of cut both for reaper harvesting and manual harvesting were measured from the base of stem to the tip of the top cutting tip. All data were taken at five randomly selected places within each plot and average data were taken.

2.2.3.2. Operating Speed

Forward speed was calculated to measure the theoretical field capacity of the reaper which is determined by marking the length of 20m and the reaper was operated in the marked run length. A stop watch was used to record the time for the reaper to travel the marked run length so that the operation speed was calculated from the time required for the machine to travel the distance of 20m. The operating speed was calculated using the following formula:

$$S = \frac{3.6 * d}{t} \quad \ldots(1)$$

Where: S = operating speed, km/h

d = distance, m

t = time, s

2.2.3.3. Theoretical field capacity

Theoretical field capacity was measured based on operating speed and the cutting width of the reaper. It was determined using the following formula:

$$\text{Theoretical field capacity, ha } h^{-1} = \frac{\text{Width (m)} \times \text{Speed (km/h)}}{10} \quad \ldots(2)$$

2.2.3.4. Actual field capacity

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Actual field capacity was computed from the area covered by the reaper and based total time, including turning loss, operator personal loss, machine adjustable loss and troubleshooting loss during field operation. It was determined using the following formula:

$$\text{Effective field capacity,ha h}^{-1} = \frac{\text{Total area covered,ha}}{\text{Total time taken,h}} \quad \ldots(3)$$

2.2.3.5. Field efficiency

Field efficiency is computed from the ratio of actual field capacity and the theoretical field capacity and expressed in percent. It was determined using the following formula:

$$\text{Field efficiency,\%} = \frac{\text{Effective field capacity,(ha/h)}}{\text{Theoretical field capacity,(ha/h)}} x100 \quad \ldots(4)$$

2.2.3.6. Fuel Consumption

The fuel consumption was measured by refill method. In this method, before the start of each test trial, the fuel tank was filled to its full capacity and after each test trial; the tank was refilled using graduated cylinder keeping the tank horizontal so as not to leave empty space in the tank. The quantity of refilled fuel was expressed in liters per hour (L/h). It was determined using the following formula:

$$F_c = \frac{q}{t} \quad \ldots(5)$$

Where: Fc = Fuel consumption (l/h)

q = quantity of refilled fuel (l)

t = consumption time (hr)

2.2.3.7. Grain losses

Pre harvest grain loss and harvesting grain losses were measured for each plot at three randomly selected points by a metal square frame (1×1 m) and the mean values were presented in (g/ m^2).

i. Pre-harvest losses

Pre harvesting loss was collected from an area of $1m^2$ was harvested manually using a sickle. Care was taken that there were no shattering losses. The grains and ear heads, which had fallen within $1m^2$ metal frame were collected and weighed. This pre harvest loss (W1) in g/m^2 was repeated at five different places chosen randomly in every plot.

ii. Shattering loss

Shattering loss is the amount of grains and ear heads fallen on the ground due to harvesting actions. After harvesting, grains and ear heads which has been fallen within $1m^2$ metal frames was recorded. This shattering loss (W_2) was repeated at five different places chosen randomly within a plot.

iii. Conveying loss

Conveying loss is the amount of grain and ear heads fallen during harvesting and bundling of the crop. To measure this loss a canvas of (2 *1 m) was laid and securely fastened to the ground on the adjacent to the standing crop. The harvested crop fell on the canvas sheet was collected carefully all the grains and ear heads on the canvas sheet as a result of shaking during harvesting were recorded as conveying loss (W_3) in g/m^2.

iv. Percentage of harvesting loss

Harvesting loss was determined before and after harvesting at different stages by manual cutting and with reaper, the percentage of harvesting losses was determined by using following formula (Pradhan *et al*., 1998):

$$W_t = W_1 + W_2 + W_3 \quad \ldots(6)$$

$$H = \frac{W_t - W_1}{Y_g} x100 \quad \ldots(7)$$

Where: - W_t = Total losses, g m^{-2}

W_1 = Pre-harvest losses, g m^{-2}

W_2 = Shattering losses, g m^{-2}

W_3 = conveying losses, g m^{-2}

H = Percentage of harvest losses, %

Y_g = Grain yield, g m^{-2}

2.2.3.8. Harvesting Cost

The harvesting cost with reaper includes fixed and variable cost. Comparison was done between manual and reaper harvesting costs of wheat. The production price of the reaper and purchase price of engine was estimated as 57950 birr. The useful life of the reaper was considered 10 years. The machine salvage value was considered 10% of the purchase value.

i. Fixed Costs

Fixed cost of the machine is the cost which is involved irrespective of whether the machine is used or not. It 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).

$$\text{The annual Depreciation, } D = \frac{P - S}{L} \quad \ldots(8)$$

Where, P = purchase price (Birr),

S = selling price (Birr),

L = Useful life, yr.

Interest is a cost on the investment of agricultural machinery and was calculated by the following formula:

$$\text{Interest on Investment, I} = \frac{P+S}{2} i \qquad \ldots(9)$$

Where, P = Purchase price, Birr.

S = Resale value, Birr.

i = annual interest rate

Tax, insurance and shelter costs were considered 2.5 % of purchase price of the reapers.

$$\text{Shelter, Tax and Insurance, STI} = 2.5\% p \qquad \ldots(10)$$

Total fixed cost of the machine was annually estimated as follows:-

$$\text{Total Fixed Cost}\left(\frac{\text{Birr}}{\text{Yr}}\right) = D + I + \text{STI} \qquad \ldots(11)$$

$$\text{Fixed Cost}\left(\frac{\text{Birr}}{\text{ha}}\right) = \frac{\text{Total Fixed Cost}\left(\frac{\text{Birr}}{\text{Yr}}\right)}{\text{Total Area Coverage}\left(\frac{\text{ha}}{\text{Yr}}\right)} \qquad \ldots(12)$$

ii. Variable Costs

Variable cost of the reaper includes: cost of fuel, lubrication, labor, and repair and maintenance costs. These costs increase with increased use of the reaper and vary to a large extent in direct proportion to hours or days of use per year and determined by the following formulas:-

$$\text{Fuel Cost}\left(\frac{\text{Birr}}{\text{ha}}\right) = \frac{\text{Fuel consumed}\left(\frac{\text{Litre}}{\text{Day}}\right) \times \text{Pr}ice\left(\frac{Birr}{Litre}\right)}{\text{Area Coverage}\left(\frac{\text{ha}}{\text{Day}}\right)} \qquad \ldots(13)$$

$$\text{Lubrication Cost}\left(\frac{\text{Birr}}{\text{ha}}\right) = 15\% \text{ of fuel cost} \qquad \ldots(14)$$

$$\text{Loubor Cost}\left(\frac{\text{Birr}}{\text{ha}}\right) = \frac{\text{Sum of wages of loubors}\left(\frac{\text{Birr}}{\text{Day}}\right)}{\text{Area Coverage}\left(\frac{\text{ha}}{\text{Day}}\right)} \qquad \ldots(15)$$

$$\text{Repaire and Maintenanc, R \& M}\left(\frac{\text{Birr}}{\text{Yr}}\right) = 3.5\% \text{ of purchase price} \qquad \ldots(16)$$

$$\text{Total Variable Cost}\left(\frac{\text{Birr}}{\text{ha}}\right)=(\text{F}+\text{O}+\text{L}+\text{R}\,\&\,\text{M})\frac{Birr}{ha} \quad \ldots(17)$$

$$\text{Total cost of Harvesting}\left(\frac{\text{Birr}}{\text{ha}}\right)=\text{Fixed cost}\left(\frac{\text{Birr}}{\text{ha}}\right)+\text{Variable cost}\left(\frac{\text{Birr}}{\text{ha}}\right) \quad \ldots(18)$$

iii. Break-even point

A break-even point (BEP) defines when an investment generate a positive return and can be determined with simple mathematics or graphically. It is, useful tool to study the relationship between operating costs and returns and the intersection point at which neither profit nor loss is occurred The BEP analysis was done considering the actual cost of operation with the reaper and cost of manual harvesting using following formula Alizadeh *et al.* (2013):

$$\text{Break-even point, B}=\frac{F}{V_a-V_m} \quad \ldots(19)$$

Where: - B = Break – even point (ha/year),

F= Fixed costs of machine harvesting (Birr/year)

V_a= Variable costs for manual method (Birr/ha)

V_m= Variable costs for machinery method (Birr/ha)

3. Results and Discussion

Performance data were collected to assess operating speed, field capacity, field efficiency, losses due to machine operation, fuel consumption and labor requirement. During field operation several agronomic data were taken. All the data taken were the average value by making trial for three plots.

3.1. Crop characteristics

The mean values of plant height, number of tillers, plant population and height of cut were measured before harvesting operation to control operation speed and cutting height of the reaper obtained from each plot are shown in table 2.

Table 2. Crop characteristics of experimental plots

Crop parameter	Reaper harvesting	Manual harvesting
Height of plant , cm	107.67	107.67
Number of tillers	5	5
Plant population per sq. m	320	320
Height of cut, cm	36	45
Condition of crop	erect	erect
Moisture content, %	10.27	10.27

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

3.2. Machine Performance parameters

The machine was evaluated for wheat harvesting. The average value of some of the parameters including effective cut width, forward speed, total operation time, theoretical field capacity, effective field capacity, field efficiency, fuel consumption and harvesting losses were presented in Table 3 below.

Table 3. Test results of reaper harvester compared with manual harvesting by sickle

Parameter	Reaper harvesting				Manual harvesting
	T1	T2	T3	Average	
Actual area covered (ha)	0.03	0.03	0.03	0.03	0.03
No. of Labours	1	1	1	1	5
Total time of operation (min)	24.52	25.00	25.49	26.00	46.45
Effective working width (cm)	50	50	50	-	-
Operating speed (km/hr)	2.12	2.15	2.17	2.15	-
Theoretical field capacity (ha/hr)	0.106	0.108	0.109	0.108	-
Effective field capacity (ha/hr)	0.073	0.072	0.071	0.072	0.008
Field efficiency %	68.90	66.70	65.10	66.9	-
Labour requirement, man-hr/ha	13.70	13.89	14.10	13.89	125
Fuel consumption (lit/hr)	1.09	1.12	1.07	1.09	-
Potential grain Yield (gm/m^2)	670.32	650.72	678.19	666.41	666.41
Harvesting losses (g/m^2)	20.19	18.93	21.85	20.33	21.69
Harvesting losses (%)	3.00	2.90	3.20	3.03	3.30
Conveying loss (g/m^2)	9.46	8.88	8.89	9.08	6.97
Conveying loss, %	1.40	1.40	1.30	1.37	1.00
Total harvesting loss, %	4.40	4.30	4.50	4.40	4.30

Reaper performance was measured in terms of theoretical field capacity, actual field capacity and field efficiency of the reapers. Table 3 presents the mean values of field performance results of reaper for wheat crop. The cutting width was 0.5 m and the operating forward speed of the machine was found 2.15 km/h. The results presented in table 3 showed that the theoretical field capacity, actual field capacity and field efficiency of the reaper was 0.108ha/h, 0.072ha/h and 66.90%, respectively. Result of fuel consumption of the reaper showed that 1.09 L/h at forward speed of 2.15 km/h. In manual harvesting with sickle, on average one person can harvest 80m^2 /hr, but this amount can be differ with respect to crop condition, laborer ability and weather condition. The required time for harvesting one hectare of wheat in manual harvesting was 125 man-h/ha compared to 13.89 man-h/ha for the reaper (Table 3). The reaper was 9 times faster compared to manual harvesting.

3.3. Harvesting Losses

The mean values of grain loss due to harvesting and conveying losses for reaper and manual harvesting with sickle are shown in table 3. The mean percentage values of conveying and harvesting losses of the reaper were found

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1.37% and 3.03%, respectively and that of manual harvesting of 1.00% and 3.30% were recorded respectively for conveying and harvesting losses. Total harvesting loss of the reaper was found higher compared to manual harvesting method (table. 3). The higher harvesting loss of reaper may happen due to unleveled field and operator's skill. Similar results were reported by Singh *et.al.* (1988). Devani and Pandey (1985) designed and developed a vertical conveyor belt windrower for harvesting wheat crop. They concluded that, the total harvesting losses were in the range of 4 to 6 % of grain yield when grain moisture content was 7 to 11 %.

3.4. Cost Analysis

The estimated production cost of the reaper including engine costs are 56,950birr. The amount of total costs of the reaper including fixed costs and variable costs are shown in Table 4. The annual working hour of the reaper was considered 240 hours, so, the fixed and variable costs were 469.63birr/ha and 1,032.15birr/ha respectively. In this study, manual harvesting required 16 man-days to harvest one hectare of wheat field. Considering the labor cost as 200birr per day, 3200 birr/ha was required for manual harvesting, whereas 1,501.78 birr/ha was calculated for reaper harvesting (Table 4).

Table 4. Estimated total cost of reaper and manual harvesting for wheat

Particulate	Reaper harvesting cost			Manual harvesting cost	
Cost items	**Birr/Year**	**Birr/ha**	**Birr/hr**	**Birr/ha**	**Birr/hr**
Fixed cost					
Depreciation	5,125.50	296.50	21.35	3,200	25.60
Interest	1,566.12	90.64	6.53		
Taxes, insurances and shelter	1,423.75	82.34v	5.93		
Total fixed cost	8,115.37	469.63	33.81		
Variable cost					
Fuel	8,527.20	493.56	35.53		
lubrication	1,276.80	74	5.32		
labor	5,997.60	347.22	24.99		
Repair and maintenance	2,028.25	117.37	8.45		
Total variable cost	17,829.85	1,032.15	74.29		
Harvesting cost	25,945.22	1,501.78	108.10	3,200	25.60

Net savings per hectare area (Table 5) of 1,464.98Birr/ha could be saved as compared reaper harvesting against manual harvesting. This net saving comes because of higher field capacity of reaper than manual harvesting. In a previous study, net savings (1770 Bhat/ha) was found by Bora and Hansen (2007) who harvested wheat by a reaper (40 Bhat = 1US$).

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Table 5. Comparison of savings by the reaper harvesting per hectare

Particulars	Calculation	Amount (Birr)
Cost of manual harvesting (16 man-days/ha)	16×200	3,200
Cost of reaper harvesting/ha	1,501.78	1,501.78
Gross savings	3,200−1,501.78	1,698.22
Cost of total output (6664 kg/ha @ 35 birr/kg)*	35×6664	233,240
Loss in reaper harvesting, (4.40%)	233,240×0.044	10,262.56
Loss in manual harvesting (4.30%)	233,240×0.043	10,029.32
Excess loss due to manual harvesting	10,029.32 - 10,262.56	-233.24
The net savings per hectare	1,698.22 + (-233.32)	1,464.98

*Considered the production of wheat 66.64 quintal per hectare.

3.5. Break-even Point Analysis

The harvesting cost (without binding and threshing) was 1,501.78birr/ha for walking behind reaper and 3200birr/ha of manual harvesting. The break-even point of the reaper is found 3.74 which is the point where the cost of reaper harvesting and manual harvesting would be the same. It shows that the harvesting cost of reaper decreases with the increase in annual use coverage. It means that the reaper would be economical to the farmers when the annual use exceeds 4 hectare of land.

3.6. Conclusions and Recommendations

3.6.1. Conclusions

Harvesting is one of the labor intensive and tedious works of wheat production. The studied reaper was found suitable for harvesting wheat in leveled condition. The performance of the reaper with respect to field capacity, field efficiency, fuel consumption, harvesting losses, labour requirement and cost of operation were studied and compared with manual harvesting method and the following conclusions are drawn. 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 feasible solution for reducing the cost of harvesting of wheat crops in Ethiopia with labor saving and minimize human drudgery problems of marginal farmers.

3.6.2. Recommendations

1) From the study it was found that the use of reaper was beneficial than manual harvesting for harvesting of wheat

2) The present study is carried out only for wheat cutting, but the same machine can be applied for harvesting rice.

3) Increasing width of cut in order to increase field efficiency of the machine.

4) Adding crop binding part to the machine may increase acceptability of this machine.

Declarations

Source of Funding

This research was funded by the Oromia Agricultural Research Institute.

Competing Interests Statement

The authors have declared that no competing financial, professional, or personal interests exist.

Consent for publication

All the authors contributed to the manuscript and consented to the publication of this research work.

Authors' contributions

All the authors took part in literature review, analysis, and manuscript writing equally.

Availability of data and materials

Supplementary information is available from the authors upon reasonable request.

Institutional Review Board Statement

Not applicable for this study.

Informed Consent

Not applicable for this study.

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