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RESEARCH ARTICLE

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EVALUATION OF WALKING BEHIND HARVESTER FOR WHEAT CROP

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ABSTRACT
The walking behind harvester (TNS Model 4S-120 imported) was evaluated for its performance by harvesting of wheat crops. The field evaluation was carried out at Kulumsa Agricultural Research Center experimental site. Parameters and measurements considered during this study were crop parameters, operating parameters of the harvesting machine, harvesting losses and cost of harvesting. The average effective field capacity and field efficiency of the harvester was found to be 0.182 ha/h and 81% respectively whereas the effective field capacity in manual harvesting was 0.008 ha/h. Fuel consumption of the reaper was 0.92 lit/h, 5.08 lit/ha. Average value of harvest losses in mechanical harvesting was 1.42 percent only whereas average value of harvesting losses in manual harvesting was 1.73% which is more than that of mechanical harvesting. The cost of harvesting for harvester and for manual harvesting were 479Birr/ha and 1600Birr/ha respectively. The percent saving in the cost of harvesting is reduced by 30% harvesting of wheat with harvester over manual harvesting. Hence, the machine harvesting would be feasible and economical compared to manual harvesting method in terms of time, money and labor requirement.
Keywords: walking behind harvester, field capacity, field efficiency, harvesting lose.

INTRODUCTION

Ethiopia is an agrarian economy with a mainly rain fed agricultural system, where wheat (*Triticumvulgare*) and barley are among the main cereal crops which contribute about 68.3% of the national food grain production (CSA, 2008). Ethiopia is the second largest wheat producing country in Africa followed to South Africa. Wheat is mainly grown in the central and south eastern highlands during the main (Meher) rainy season (June to September) and harvested in October-November. Arsi, Bale, and parts of Shoa are considered the wheat growing belt.

Harvesting is one of the most important operations of farming activities. Most of the parts of the country have been harvesting manually. This is a labour intensive seasonal operation consuming about 18-20% of the Labour required for growing cereal crops (Singh *et al.,* 2008). The traditional method of harvesting with sickle is both labour as well as time consuming, where both are scarce during the peak harvesting season. Labour scarcity during peak period of harvesting leads to delay in harvesting and field grain losses. Also high labour cost during peak period adds extra cost in total cost of harvesting.

Mechanized harvesting is an alternative solution to tackle this problem. As a step towards mechanization of the harvesting operation for cereal crops, the alternatives available were considered such as self-propelled combine harvesters and tractor mounted combine harvesters. The uses of combine harvesters have

their limitations. The farmers want to recover both grains as well as the straw from wheat crops, because the straw is main source of feeds of the cattle. Moreover, Ethiopian farmers' fragmented and small farm size holdings, over 69 percent of smallholder farmers in the cereal growing own farmlands less than or equal to one hectare (CSA, 2013). However, high level harvesting combine harvester is not affordable for them.

Most of the cereal crops are harvested by sickle which is quite tedious and labour-intensive job. During the peak season of harvesting, farmers face the difficulty of getting their crop timely reaped due to shortage of agricultural labourers. Non-availability of labor due to increased rural-urban migration. Hence, keeping these facts in view, this study was conducted to evaluate the performance of the walking behind harvester machine and introduce technology options, to minimize the cost of harvesting through farm mechanization.

MATERIAL AND METHODS

The experiment was conducted at Kulumsa Agricultural Research Center (KARC) research farm near the city of Asella in 2015/16 cropping season. Wheat harvesting was performed manually with sickle and with mechanical harvester. The detailed manufacturers technical specifications of walking behind harvester used for field performance evaluation used are presented below in table 1:-

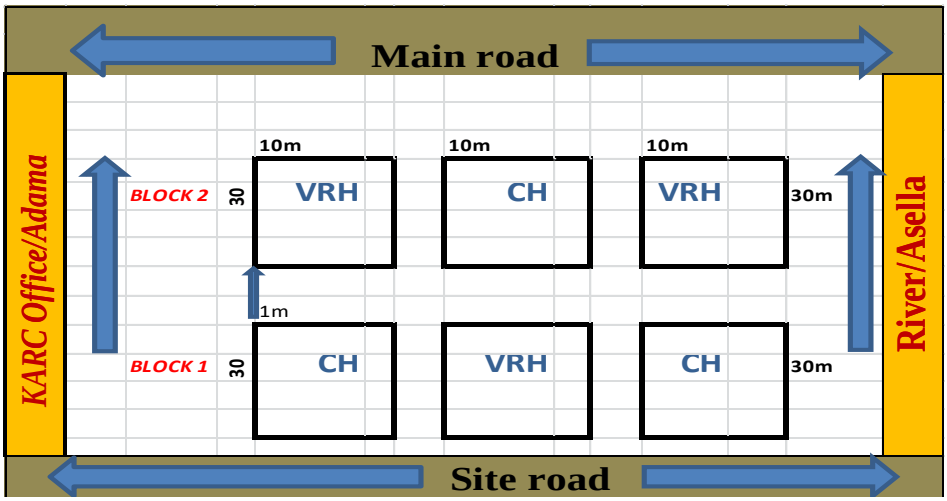
Table 1. Technical specification of vertical conveyor walking behind reaper

No.	Parameters	Specifications
1	Manufacturers	ZHEJING TING SHENG MACHINE CO. LTD.
3	Model	TNS-4S-120
4	Dimensions(L x W x H) cm	239 x 147 x 90
5	Weight (kg)	165
6	Power unit	5.5 HP single cylinder 4 stroke, air cooled, petrol start, kerosene run engine
7	Working capacity (ha/hr)	0.25
8	Crop release	Right side of the machine (viewed from rear)
9	Operating speed (km/hr)	2
10	Applicability	Dry land
11	Cutting device	Reciprocating cutter bar
12	Cutting height (cm)	10-30 from ground level
13	Cutting width (cm)	120

Field Experiment

Experimental plot size of 300m^2 was harvested by mechanical harvester and manual with sickle and replicated three times for each as shown in figure 1(experimental lay out). The area of the plot was measured with tape. Also randomly three small areas were selected in the plot for determining shattering loss. To calculate the operational speed of harvester, time was recorded that was taken to travel a certain distance. The distance was measured with a measuring tape and time was counted with a stop watch. Such operations were done in several times to calculate the average speed of operation. The actual field capacity was calculated by dividing the total area harvested by total time taken to harvest a certain

plot. The theoretical field capacity was calculated by the formula.



*-Figure 1 Experimental plot lay out of wheat fields

Performance of the Machine

Harvesting Losses

In order to estimate harvesting losses in manual and reaper harvesting, losses that occur before harvesting (pre-harvest) was collected and measured. Harvesting losses include shattering and uncut losses were determined by the following equation (Pradhan, 1998):-

$$W_{gt} = w_{g1} + w_{g2} + w_{g3} \quad 1$$

Where:- W_{gt} = Total grain losses (g/m^2), w_{g1} = Pre-harvest grain loss (g/m^2), w_{g2} = Grain loss from uncut panicle (g/m^2) and w_{g3} = Shattering grain loss (grain from cut panicle but fallen and grain loss on ground) (g/m^2)

After measuring the amount of losses at different stages, the percentage of harvesting loss was determined by the following equation (Pradhan, 1998):-

$$H_L = \frac{W_{gt} - w_{g1}}{W_{gpy}} \times 100 \quad 2$$

Where: - H_L = Harvesting grain loss (%), Wg_1 = Pre-harvest grain loss (g/m^2),W_{gt} = Total grain losses (g/m^2) and W_{gPy} = Potential yield (g/m^2)

Conveying Loss

In order to estimate conveying losses in manual and reaper harvesting five sets of sample were taken using a canvass spread of 2m length on a place where cut stalks were fall. Detached grains from the panicle was collected and recorded. Percentage of conveying loss was determined by the following equation:-

$$C_L = \frac{L_C}{W_{gpy}} \times 100 \quad 3$$

Where: C_L = Conveying loss (%), L_C = Average conveying loss (g/m^2), W_{gPy} = Potential yield (g/m^2)

Total machine Loss

After determining the amount of different harvesting losses of the machine, the percentage of total harvesting loss of the machine was determined by the following equation:-

$$T_L = H_L + C_L \quad 4$$

Where: - T_L = Total machine loss (%), H_L = Harvesting loss (%) and C_L = Conveying loss, %

Machine Performance

Forward speed of the machine was determined to compute the theoretical field capacity of the harvesting machine. Total operation time and lost time (turning time loss, operator personal time loss and machine adjustable time

loss) during field operation was recorded to calculate the actual field capacity of the machine. The following formulas were used to compute theoretical field capacity, actual field capacity and field efficiency.

Theoretical field capacity was calculated based on the speed of operation and cutting width of the harvester as follows (R. Jaya Prakash et al, 2015):-

$$F_{CT} = \frac{W_C \times S_O}{10} \quad 5$$

Where: F_{CT} = Theoretical field capacity (ha/h) W_C = Cutting width (m) and So = Operating speed, km/h

Actual field capacity was computed based on area covered and actual time taken for covering the given area including the time lost during operation as follows:

$$F_{CA} = \frac{A_T}{T_t} \quad 6$$

Where: F_{CA} = Actual field capacity (ha/hr), A_T = Area covered during test (ha), T_t = Total operating time, hr

The field efficiency was obtained from the ratio of the actual field capacity to the theoretical field capacity of the machine and expressed in percent as follows:-

$$E = \frac{F_{CA}}{F_{CT}} \times 100 \quad 7$$

Where: E = Field Efficiency (%), F_{CA} = Actual field capacity (ha/h), and F_{CT} = Theoretical field capacity, ha/h

Cost Analysis

Harvesting cost of the harvester included cost of labor, machine depreciation, machine repair, fuel and lubricants. Labor cost included wages for the machine operator and the assistant operator. The harvesting cost for harvester is calculated on the basis of fixed and variable costs. The local purchase price of the reaper was 52,000birr.

Fixed Costs

Fixed cost of the machine is the cost which is involved irrespective of whether the machine is used or not. These costs include; Depreciation cost, interest on investment and taxes, shelter and insurance. Depreciation cost was calculated by straight line method. Useful life of harvester considered to be 10 years. The salvage value was also considered to be 10% of purchase price.

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

Where, P = purchase price (Birr), S = selling price (Birr), L = Useful life, yr.

Interest on Investment is an actual cost in agricultural machinery and was calculated by Straight Line Method.

$$\text{Interest on Investment, I} = \frac{P + S}{2} i \quad 9$$

Where, P = Purchase price, Birr. S = Resale value, Birr. i = annual interest rate Shelter, Tax and Insurance cost of the machine were annually estimated as follows:-

$$\text{Shelter, Tax and Insurance, STI} = 2.5\% p \quad 10$$

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

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

Variable Costs

Fuel, oil, labor, repair and maintenance cost were considered as variable costs of the machine and determined by the following formulas:

$$\text{Fuel Cost}\left(\frac{\text{Birr}}{\text{ha}}\right) = \frac{\text{Fuel consumed}\left(\frac{\text{Litre}}{\text{Day}}\right) \times \text{Price}\left(\frac{Birr}{Litre}\right)}{\text{Area Coverage}\left(\frac{\text{ha}}{\text{Day}}\right)} \quad 13$$

$$\text{Oil Cost, O}\left(\frac{\text{Birr}}{\text{ha}}\right) = 15\% \text{ of fuel cost, F} \quad 14$$

$$\text{Loubor Cost, L}\left(\frac{\text{Birr}}{\text{ha}}\right)=\frac{\text{Some of wages of loubors}\left(\frac{\text{Birr}}{\text{Day}}\right)}{\text{Area Coverage}\left(\frac{\text{ha}}{\text{Day}}\right)} \quad 15$$

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

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

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

Break-Even Point

The break-even point is that area in which the harvesting cost per unit area is equal for machine and manual, determined by the following equation described by Alizadeh *et al.,* (2013).

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

Where, B = Break – even point (ha/year), F = Fixed costs of Machine (Birr/year) V_a = Variable costs for manual method (Birr/ha) V_m = Variable costs for machinery method (Birr/ha)

RESULT AND DISCUSSION

The walking behind harvester was evaluated for its performance by harvesting of wheat during *2015/16 harvesting season*. The experiments were carried out in the extent of 0.18 ha at Kulumsa Agricultural Research Center of research farm. Parameters and measurements considered during this study were crop parameters, machine performance parameter, harvesting losses and cost of operations. The results of field performance based on test conducted are summarized in Table 2 and 3.

Table 2. Details of crop parameters

Particulate	Harvesting Methods				
	Mechanical harvester				Manual harvesting
	Trial			Mean value	
Crop	Wheat				Wheat
Height of plant , cm	97.2	89.6	87.9	91.6	90.2
Number of tillers per sq. m	252	243	287	261	261
Height of cut, cm	20	13	15	16	32
Condition of crop	erect	erect	erect	-	erect
Grain moisture content, %	8.9	8.6	8.7	8.73	8.73
Straw moisture content, %	8.32	8.47	8.47	8.42	8.42

Machine Performance

Measurements of harvester performance for wheat crop were the rate and quality of the machine at which the operations are accomplished. The mean value of the performance parameter that include time losses; total working time, test plot area, cutting width, cutting height, operating speed, theoretical field capacity, actual field capacity and field efficiency are shown in Table 3. The cutting width was 1.2 meter and the operating forward speed of the machine was found 1.87 km/h. The actual field capacity of the reaper for wheat crop was 0.182 ha/h. The theoretical field capacity of the machine is a function of speed of travel and cutting width and computed result is 0.225ha/h. Field efficiency of reaper harvesting machine was 81%. In manual harvesting with sickle, a laborer on average can harvest 80 m^2 /hr, but this amount can differ with respect to crop condition, laborer ability and weather condition. The required time for harvesting one hectare of wheat in manual harvesting was 123.33 man-h/ha compared to 5.5 man-h/ha for the harvesting (Table 3). The harvester was 22.42 times faster compared to manual harvesting.

Table 3: Test results of mechanical harvester compared with manual harvesting by sickle

Parameter	Harvesting Methods				
	Mechanical harvester				Manual harvesting
	Trial				
	1	2	3	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)	10.25	9.45	10	9.73	44.40
Effective working width (cm)	120	120	120	-	-
Forward speed (km/h)	1.95	1.78	1.88	1.87	-
Theoretical field capacity (ha/hr)	0.234	0.214	0.226	0.225	-
Actual Field capacity (ha/hr)	0.175	0.190	0.180	0.182	0.008
Field efficiency %	74.78	88.78	79.64	81	-
Labour requirement, man-hr/ha	5.69	5.25	5.56	5.5	123.33
Fuel consumption (lit/hr)	1.06	0.79	0.92	0.92	-
Fuel consumption (lit/ha)	5.83	4.33	5.08	5.08	-
Potential grain Yield (gm/m^2)	533.95	482.87	606.18.	541	541
Harvesting losses (g/m2)	5.85	7.50	6.60	6.65	7.99
Harvest losses (shattering + Uncut) %	1.10	1.55	1.08	1.22	1.48
Conveying loss (g/m2)	1.10	1.19	1.04	1.11	1.37
Conveying loss, %	0.20	0.24	0.17	0.20	0.25
Total harvesting loss, %	1.30	1.79	1.25	1.42	1.73

Harvesting Losses

The measured values of harvesting, conveying losses and total harvesting (conveying and harvesting) losses for wheat in reaper and manual harvesting methods are presented in Table 2. The mean percentage of conveying losses in reaper and manual harvesting for wheat crop were 0.20% and 0.25% respectively and that of harvesting losses were 1.22% and 1.48% respectively. The total losses in reaper and manual harvesting were 1.42% and 1.73%. In earlier study, S.S. Karahle (2015) reported that 0.93% harvesting loss during harvesting of wheat by self-propelled reaper binder against 1.83% loss of manual harvesting.

Economic Analysis

The local purchase price of the reaper was 52,000birr. The annual fixed cost (7410 Birr) and variable cost (68.34Birr/h) were found from the calculation. The working hour of the reaper was considered 416 hours per year. The fixed cost and variable costs for both reaper and manual harvesting are presented in Table 3. In this study, manual harvesting required 16 man-days to harvest one hectare of wheat field. Considering the labor cost as 100Birr per day, 1600 Birr/ha was required for manual harvesting, whereas 479.01 Birr/ha was calculated for reaper harvesting (Table 3).

Net savings per hectare area as shown in Table 4, indicate that 1,251.91 Birr/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 field capacity. In a previous study, net savings (1770 Bhat/ha) was found by Bora and Hansen (2007) who harvested rice by a reaper (40 Bhat = 1US$).

Table 3: Harvesting cost of reaper and manual harvesting

Machine harvesting cost				Manual harvesting cost	
Cost items	Birr/Year	Birr/ha	Birr/hr	Birr/ha	Birr/hr
Fixed cost					
Depreciation	4,680	62.55	11.25	1600	12.50
Interest	1,430	19.13	3.44		
Taxes, insurances and shelter Total	1,300	17.40	3.13		
fixed cost	7,410	99.08	17.82		
Variable cost					
Fuel	14,094.08	188.35	33.88		
lubrication	2,114.11	28.25	5.08		
labor	10,400	139	25		
Repair and maintenance	1,820	24.33	4.38		
Total variable cost	28,428.19	379.93	68.34		
Total cost of harvesting	35,838.19	479.01	86.16	1600	12.5

Table 4**:** Comparison of savings by the reaper harvesting per hectare

Particulars	Calculation	Amount (Birr)
Cost of manual harvesting (16 man-days/ha)	16×100	1600
Cost of machine harvesting/ha	479.01	479.01
Gross savings	1600 – 479.01	1,120.99
Cost of total output (5400 kg/ha @ 8 birr/kg)*	8×5400	43,200
Loss in reaper harvesting, (1.42%)	43,200 ×0.0142	613.44
Loss in manual harvesting (1.73%)	43,200 ×0.0173	747.36
Excess loss due to manual harvesting	747.36 – 613.44	133.92
The net savings per hectare	1,120.99 + 133.92	1,251.91

*Considered the production of wheat 54 quintal per hectare

Break-even Point Analysis

Harvesting cost by a reaper is found to be decreased gradually with the increase of harvesting area. However, break-even point is 6 ha of land where same cost will be found for both of reaper and manual harvesting. This break-even point indicates that reaper would be beneficial to the farmers when the area of the harvesting land is more than 6 hectare of land per year.

SUMMERY AND CONCLUSIONS

Based on the field performance evaluation harvester conducted during harvesting season of 2016/17, it can be summarized as follows:-

The average effective field capacity and field efficiency of the reaper was found to be 0.182 ha/h and 81% respectively whereas the effective field capacity in manual harvesting was 0.008 ha/h. Fuel consumption of the reaper was 0.92 lit/h, 5.08 lit/ha. Average value of harvest losses in mechanical harvesting was 1.42 percent only whereas average value of harvesting losses in manual harvesting was 1.73% which is more than that of mechanical harvesting.

The cost of harvesting for reaper harvester and for manual harvesting were 479Birr/ha and 1600Birr/ha respectively. The percent saving in the cost of harvesting is reduced by 30% harvesting of wheat with reaper harvester over manual harvesting. For economic justification of machine application, the yearly capacity of machine must not be less than 6ha/year. It can be conclude that, the use of harvesting is much more economic and efficient for harvesting of wheat compared to manual harvesting method. Therefore in fields where the use of walking behind harvester is possible, it will play an important role in reducing production costs.

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