

A NOVEL APPROACH TO OPTIMIZE HARVESTING LOSSES USING MODIFIED ENGINE OPERATED REAPER

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Agriculture production can be enhanced by considering all the farm operations especially the harvesting of crops is the more sensitive operation. The selection of appropriate farm machinery for harvesting not only save the harvesting time but also enhance the farm profitability. The agro-climatic and economic factors are the major hindrance on the way to adopt the harvesting machinery and latest movers in Pakistan. The objective of this work was to redesign an engine operated reaper at affordable price and performance evaluation of this reaper for harvesting three different crops (wheat, rice and brassica). Three levels of reaper ground speed (S) (1.94, 2.54 and 3.18 kmh⁻¹) and three different levels of moisture contents (MC) for each crop were considered as factors. A (3 x 3) factorial analysis was conducted to see the impact of "MC" and "S" on percent slippage, field efficiency and shatter losses. The main effects of S and MC were significant for all the crops for each factor (p<0.05), except MC which was non-significant for shatter losses in wheat and rice (p= 0.0667) and (p=0.847), respectively. Statistical Analysis showed that selected levels of MC and S had significant effect on % slippage, field efficiency and shatter losses. The cost analysis indicated that the breakeven point of the modified reaper can be achieved after 19 days of purchase. Study demonstrated that grain losses can be minimized, and farm profitability can be maximized by selecting suitable combination of M and S.

Keywords: Multi crops; harvesting machinery; engine operated reaper; slippage, shatter losses and efficiency.

INTRODUCTION

Government of Pakistan is imposing heavy taxes on importing the farm machinery which reduces the adoption of advance machinery in Pakistan. Agriculture sector is the back bone of Pakistan economy with 22 million hectares cropped area. Agricultural sector contributes 24 % share of gross domestic production (GDP) and provides livelihood for 48 % of labor force of this country (Zaheer, 2013; Roohi, 2007). According to FAO (2004) report, about 67% population of Pakistan is residing in rural areas and their income is attached with agriculture sector. After fulfilling the national demand of food and fiber agriculture sector is also contributing towards foreign export (Raza *et al.*, 2012).

Seeds, fertilizer, irrigation and farm mechanization are the basic inputs for any crop production system. Farm mechanization has one of the important roles from these inputs (Roohi, 2007). Rice and wheat crops are commonly harvested with traditional sickle in Pakistan, which is time consuming and laborious operation. Furthermore, labor shortage is another issue. Majority of villager's labor community is moving towards cities and overseas to get better jobs in industrial sectors (Gill, 1989).

At the time of harvesting (peak season), farmers have to pay a large amount of money for harvesting due to labor shortage (Tahir, 2003). Therefore, farmers are inclined towards harvesting machinery. Nowadays front mounted reaper is very common in Pakistan for wheat and rice harvesting, but brassica is harvested manually. Development of low-cost harvesting machines not only overcomes the shortage of labor and the on-time operations but also facilitating timely sowing and the multi cropping rotation in the country. High cost of machinery and small land holding (5-10 acres) are the major constrains for adoption of small reapers and advanced harvesting machinery in Pakistan (Tahir, 2003; Raza *et al.*, 2018).

Many researchers have evaluated the cost of mechanical harvesting with manual harvesting (Alizadeh *et al.*, 2007; Chavan *et al.*, 2015; Murumkar *et al.*, 2014; Morad *et al.*, 2007). Chavan *et al.* (2015) reported that sickle harvesting is more laborious than mechanical harvesting with reaper. Mechanical harvesting needs 50 % less labor than manual harvesting in wheat crop. They also suggested that harvesting losses can be reduced 50% by using mechanical harvester, compared with manual harvesting. Murumkar *et al.* (2014) evaluated engine operated vertical conveyor reaper. Field

capacity and cutting efficiency were found to be 0.29 ha/h and 70 %, respectively. They also reported that machine speed has significant effect on fuel consumption and crop damage. Crop damage and fuel consumption increased with increase in speed and operating cost of this reaper was found to be lower as compared to manual harvesting.

Singh *et al.* (2008) designed and fabricated a reaper (GRH-1.2) operated with engine based on a Japanese's reaper (AR12, KUBOTA, Osaka, Japan). This machine consists of three units, namely the harvest unit, the transport unit and the power unit. Parida *et al.* (2008) evaluated one tractor mounted reaper with three different engine operated reapers. They evaluated the field capacities and grain losses and concluded that tractor mounted reaper had more (0.34 ha h⁻¹) field capacity than engine operated reaper (0.19 ha h⁻¹) while 0.5 % more losses as compared with self-propelled reapers. They also evaluated the manpower requirement for harvesting manually and with reaper and found that the higher (240 h ha⁻¹) manpower required for manual harvesting compared with reaper harvesting (59-61h ha⁻¹) (Parida *et al.*, 2008).

Alizadeh *et al.* (2007) conducted an experiment to compare the performance of an engine operated reaper with manual harvesting in rice crop. Field capacity of reaper was (0.170 ha h⁻¹) significantly higher than manual harvesting (0.008 ha/h⁻¹) while less labor was required for reaper or mechanical harvesting (5.88 men-h ha⁻¹) compared with manual harvesting with sickle (5.88 men-h ha⁻¹).

Singh *et al.* (2008) improved the conveying efficiency of the existing IRRI (International Rice Research Institute) engine operated reaper by incorporating a belt attachment for cereal crops with height ranging from 1.2- 1.7 m (Sorghum, pearl millet, maize, sunflower and wheat). They also reported that the windrowing efficiency for the cut crop was 80% and cost of harvesting was 590 (Indian Rupees) IR (\$ 13.11) for the reaper and 840 IR (\$ 18.67) for harvesting with a sickle on a per hectare basis. Manjunatha and Joshi (2008) reported that the fuel consumption of a self-propelled reaper was 6.61 L ha⁻¹ with field capacity of 0.3 ha h⁻¹. The ground speed of this engine operated reaper was 3.3 km h⁻¹ with the overall harvesting efficiency of 78%.

The main objectives of the present study were to analyze the current multi-crop engine operated reaper for effective harvesting of wheat and rice crops and suggest hence some modifications /adjustments to make it suitable for long stature crops such as brassica. The high maintenance and high initial costs are the major constraints for the adoption of these small machines in Pakistan. These issues lead to the development of multi crop reaper at an affordable price in Pakistan. This study also includes the economical evaluation for this reaper which has a potential to increase the farm profit of the small land holders by reducing labor requirements for harvesting.

MATERIALS AND METHODS

Modification of Reaper and Involving Factors

Characteristics of common reaper: An engine operated reaper was divided into three main units i.e. cutting, conveying and power units. The reaper cuts the crop and places it on the side and labor manually lifts the crop and feed it into the stationary thresher for mechanical threshing. The components and the working principle of engine operated reaper is shown in Fig. 1a and Fig. 1b. Moreover, detailed drawings of sprocket, conveyor chain, Star wheel and conveyor shaft are shown in Fig. 2 and Fig. 3.

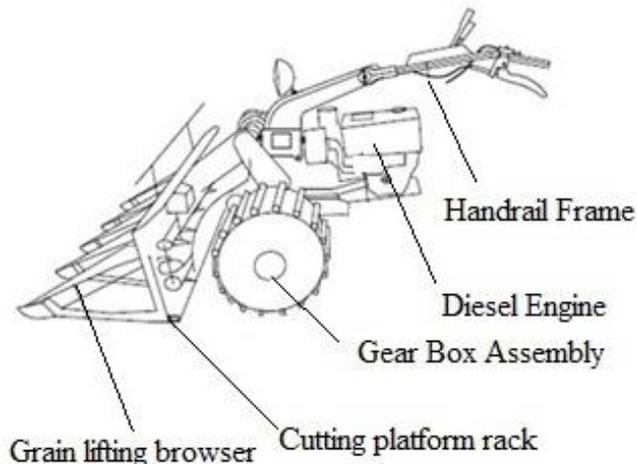


Figure 1. Schematic diagram of the engine operated reaper for harvesting wheat and rice.

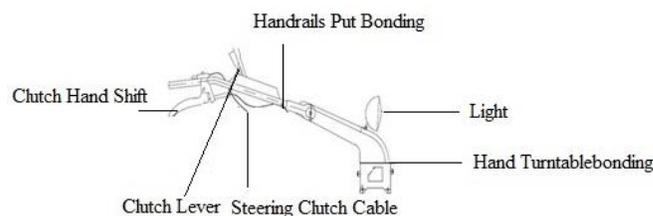


Figure 2. Handrail mechanism of the engine operated reaper (side view).

Major specifications of engine operated reaper: The overall length, width and height of this machine (Zhengzhou multi crop reaper 4SZ-120 made in Zhengzhou Shuliy Machinery Co China) is 2.33, 1.65 and 1.05 m, respectively. The swath width (cutting bar width) is 1.54 m (always less than actual width of machine). To convey the crop in one direction this reaper is equipped with two conveyer chains. The power source of this reaper is 5.74 kW diesel engine. On either side of reaper, it is equipped with two rubber tires (0.24 rim diameter, 0.40 m tire height, and 0.254 m section width).

Design modifications: The main purpose of tires was to carry the load of machine, transfer the implement forces (breaking and pull), lower the soil compaction, reduce the surface

damage, provide the damping effect to reduce the vibration of machine and reduce the wear and tear of machine.

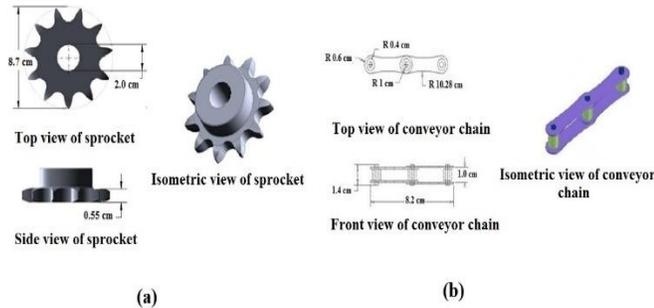


Figure 2. Auto CAD drawings for different views of sprocket (a) and conveyor chain

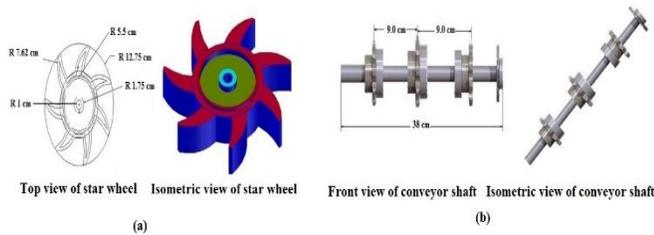


Figure 3. AutoCAD drawings for different views of star wheel (a) and conveyor shaft (b)

In the 1st experiment this reaper was used to harvest rice crop and the following problems with tires were observed i.e. more power consumption due to more contact area of tires with soil which increase the friction forces. In high soil moisture areas in rice field, it was very difficult to turn the machine with these tires. Secondly this reaper was originally designed for harvesting the cereal crops like wheat and rice. This reaper cannot be used for harvesting the tall crops like brassica and sorghum. The main problem during cutting the tall crop was, the tall crops fall down in front of reaper and stop the movement of reaper. Various efforts were made to make it suitable for harvesting the tall crops but not succeeded because of poor design.

To address these problems, the following modifications were suggested and incorporated in new designed reaper. Then it was tested for brassica and wheat crops. The design of tyres was changed with new specifications to overcome these difficulties. The new tyre design (0.54 m tyre height, 0.33 rim diameter and 0.125 m section width) was used for further testing and evaluation of the reaper.

To support the tall crops a supporting plate and a set of v-belts was added in the existing design and these belts were rolled on two pulleys (Fig. 4). The purpose of supporting plate (rectangular with dimensions of 1.45 m long and 0.60 m in width) was to hold and support the tall crops while v-belts and pulleys provide the additional support and convey the tall crop in one direction (Fig. 4). The addition of these portable/adjustable components made this reaper suitable for tall crops

harvesting without compromising its efficiency in brassica and wheat crops.



Figure 4. Improved design of engine operated reaper for tall crops in Engineering Workshop.

Factors Involving in Evaluation

Crop moisture content (MC): Crop MC was measured before harvesting by taking the 30 grams (g) of each crop at selected sampling locations in each field. The collected samples were oven dried for 24 hours at 103°C to measure the MC using the standard formula (ASAE, 1998).

$$MC = \frac{W_w - W_d}{W_w} \times 100 \quad (1)$$

where, MC is Crop moisture content in % wb; W_w as crop wet weight in g and W_d = Weight of oven dried crop (g)

Machine ground speed: Two pegs A and B were inserted at measured distance of 15 m in the selected field. The machine was started and operated along the path marked by pegs (A and B). The time taken by the machine to go from peg A to B was recorded. This procedure was replicated three times to determine the accurate ground speed. The speed was determined as follows (Tahir, 2003).

$$S = 3.6 \frac{d}{t} \quad (2)$$

Where, S is the speed in Km-h⁻¹; d is the distance between A and B pegs (m); t is the time in s to cover the distance between A and B.

Fuel consumption: Fuel consumption for machine operation was measured by filling up the fuel tank before harvesting and then again refilling it after harvesting a known area. Fuel consumption was calculated on an area basis (L ha⁻¹).

Machine slippage: Slipping is the ratio in percentage between changes in machine forward speed with load to the machine speed without load (Tahir, 2003). The % slippage was measured using the below equation:

$$\% \text{ slippage} = \frac{S_{WL} - S_L}{S_{WL}} \times 100 \quad (3)$$

where, S_L is the average ground speed with load (km-h⁻¹); S_{WL} is average ground speed without load (km-h⁻¹)

Shatter losses: To estimate the shatter losses a wooden frame of 1m x 1m was used to collect the losses. Before harvesting, the grains on the ground were collected from the selected plot (pre-harvest losses). After harvesting the fallen grains due to

the impact of machine within the frame were collected and weighed (shatter losses). The grains on the uncut plants were also collected and weighed from selected area (unharvest losses).

$$W_T = W_P + W_{SL} + W_S \quad (4)$$

where, W_T is the total grain losses in $g\ m^{-2}$; W_P is the pre-harvest losses in $g\ m^{-2}$; W_{SL} shatter losses in $g\ m^{-2}$ and W_S is unharvest losses in $g\ m^{-2}$.

The percentage of shatter losses were calculated by equation below (Alizadeh *et al.*, 2007).

$$SL = \frac{W_T - (W_P + W_S)}{Y_g} \times 100 \quad (5)$$

Where, SL is the percentage shatter losses and Y_g is the total yield of selected plot $g\ m^{-2}$.

Field capacity: Field capacity was determined by harvesting a known area in the selected fields. The observations were replicated three times to accurately determine the machine field capacity. The field capacity was calculated in $ha\ h^{-1}$ (Tahir, 2003).

$$EFC = \frac{A}{T_t} \quad (6)$$

Where, EFC is effective field capacity in $ha\ h^{-1}$; A is the area covered in ha; T_t is the total time in hr.

The theoretical field capacity was calculated in $ha\ h^{-1}$

$$TFC = \frac{W \times S}{10} \quad (7)$$

Where, TFC is the theoretical field capacity in $ha\ h^{-1}$; W is the swath width of reaper in m and S is the ground speed of machine in $km\ h^{-1}$

Field efficiency: The field efficiency is the ratio of effective field capacity to the theoretical field capacity (Tahir, 2003). The field efficiency was measured using following equation

$$FE = \frac{EFC}{TFC} \quad (8)$$

where EF is field efficiency in percentage; EFC is the effective field capacity $ha\ h^{-1}$; TFC is the theoretical field capacity in $ha\ h^{-1}$

Cost Analysis of Engine Operated Reaper: The first requirement of a newly developed machine is to perform the intended function satisfactory. However, economic aspect of machine plays a vital role in its adoption by the end user (farmers). Cost analysis was divided into fixed cost and variable cost. Fixed cost was calculated by finding out the depreciation, interest per year, housing and insurance cost. Variable cost was calculated considering repair and

maintenance cost, bundle making cost, diesel cost, lubricant cost and operator cost. The total cost of reaper was calculated by adding both fixed and variable costs.

Study site: All mechanical works were processed at the Metallurgy and Manufacturing laboratories of University of Agriculture, Faisalabad, Pakistan. The reaper was tested in the experimental zone of the Department Plant Breeding and Genetics, UAF Pakistan, with two acres' land for each crop (rice, wheat and brassica)

Design assisted by Factorial Analysis: A 3×3 factorial embedded in a completely randomized design (CRD) was employed to determine the effect of the moisture contents of crops (%) and ground speed on % field efficiency, % slippage and % shatter losses for wheat, rice and brassica crops. The collected data for grain losses was analyzed by using General Linear Model (PROC) with the help of SAS (a statistical software) (Montgomery, 2009). The LS (least square) method was used to compare the means for the treatments (statistically different) at 5 % level of probability. A 3×3 factorial experiment design was constructed for each crop using three levels of MC and three levels of S (Table 1).

As we can notice that a question arising herein is what combination for machine speed and crop moisture contents could give the least significant slippage, shatter losses and maximum field efficiency for rice, wheat and brassica crops. We tried to answer this by processing the following factorial analysis where the machine ground speed (S) and moisture contents (MC) are considered as two input factors while slippage, shatter losses and field efficiency were considered as output of this.

The model for factorial analysis is represented as follows:

$$Y_{ijk} = \mu + A_i + B_j + (AB)_{ij} + \varepsilon_{ijkl} \quad (9)$$

where i is 1 to a; j is 1 to b and k is 1 to n

In our study, a = 3 (machine ground speeds), b = 3 (crop moisture contents), and n = 3 (replications).

where Y_{ijk} is (% slippage, % shatter losses and % efficiency) same model was used for individual output; μ is overall mean; A_i is the effect of machine ground speed on response at i^{th} level; B_j is the effect of crop moisture content on response at j^{th} level and ε_{ijk} is the error terms (uncontrollable/uncontrolled factors).

Hypothesis and statistical tests: The hypothesis was segregated in two parts (i.e. hypothesis for the main effects and hypothesis for interaction effects).

Table 1. Factors of interest and their levels.

Levels	Factors			
	S ($km\ h^{-1}$)	MC % (Rice)	MC % (Wheat)	MC % (Brassica)
1	$S_1 = 1.94$	$MC_1 = 27.00$	$MC_1 = 16.70$	$MC_1 = 18.32$
2	$S_2 = 2.54$	$MC_2 = 22.00$	$MC_2 = 14.50$	$MC_2 = 16.05$
3	$S_3 = 3.18$	$MC_3 = 19.00$	$MC_3 = 13.00$	$MC_3 = 15.70$

Where, s = Machine speed, MC = Moisture Contents

Main Effects: Ho: $\alpha_1 = \alpha_2 = \alpha_3 = 0$ (α , represent machine ground speed), Ha: at least one of the treatment effects is $\neq 0$
 Ho: $\beta_1 = \beta_2 = \beta_3 = 0$ (β , crop moisture contents), Ha: at least one of the treatment effects is $\neq 0$

Interaction Effect: Two-way Interaction effects: Ho: $(\alpha\beta)_{ij} = 0$ Ha: at least one $(\alpha\beta)_{ij} \neq 0$

After checking all the assumptions normality of error term, constant variance and independence that data were analyzed by using GLM (General linear model). Twenty-seven plots (1.54 m wide and 3 m long) were selected randomly to collect data from each field. The process of randomization was used for treatment combinations within the fields to reduce the biasness of data. The impact of the crop MC and S was evaluated to determine the picking efficiency of the engine operated reaper in terms of slippage percentage, shatter losses and field efficiency. The parameters of interest were determined using standard procedures suggested in the literature.

RESULTS AND DISCUSSION

Before proceeding farther for analysis of variance (ANOVA) all three model assumptions (1. normal distribution, 2. Constant variance, 3. Independence of error terms) were tested and confirmed at 5 % level of significance. The ANOVA (Table 2) showed that the main effects of the S and MC were significant ($p < 0.05$) on % slippage for all three crops, while the interaction effect (S x MC) for all three crops was non-significant ($p > 0.05$).

In case of % shattering losses the main effect of S was found to be significant ($p < 0.05$) for all three crops while MC was non-significant ($p > 0.05$) for rice and wheat while significant ($p < 0.05$) for brassica crop. All the interaction effects of (S x MC) were significant ($p < 0.05$) for three crops on % shatter losses. For % efficiency all the main effects of S, MC and S x MC were found to be significant while only S x MC was non-significant ($p > 0.05$) for wheat crop. (Table 2). The Table 2 revealed some interesting results regarding P and F values. For rice crop the MC have maximum F value (F= 18.24) while

at the same time minimum P value ($p < 0.0001$), showed the variance between groups was significantly higher (signal) then the variance within the group (noise) in case of % slippage. Similarly, for wheat and brassica the F and P values (F= 61.84, $P < 0.0001$) for MC and (F= 20.5, $P < 0.0001$) for S were found to be more interesting for % slippage. On another hand the Table 2 reveled the non-interesting results for rice crop for % slippage, interaction S x MC with F= 0.44, P= 0.7813 had more noise as compared with signals. For % shatter losses with S for rice (F = 99.10, $P < 0.0001$), Wheat (F=44.31, $P < 0.0001$) and brassica (F=106.32, $P < 0.0001$) were found to be more interesting with significantly higher signals and less noise and vice versa. In case of rice the S, MC and S x MC were found to be significant while comparing the F-values S was more interesting with highest F-value among all three effects.

The alternate hypothesis (Ha) was found to be true for S and MC for % slippage, % shatter losses and % efficiency except MC for %shatter losses in wheat and rice crops the null hypothesis (Ho) was found to be true (Table 2). The null hypothesis (Ho) was found to be true for S x MC for rice, wheat and brassica crops for % slippage while alternate hypothesis (Ha) was found to be true for % shatter losses for three crops. For % efficiency a mixed trend was observed, for rice crop alternate hypothesis (Ha) was found to be true but for wheat and brassica null hypothesis (Ho) found true.

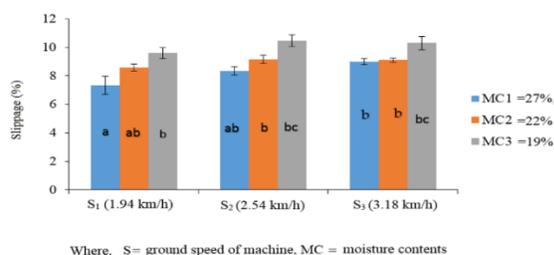
In factorial experiments, if the higher order interaction is found to be significant then we can ignore the main effects because they are the part of interaction effects. The results of the tests showed that the slippage, shatter losses and field efficiency were affected by the MC and S of the reaper either in combination or alone suggested that an appropriate combination could give better results for high field efficiency % of the engine operated reaper. Multiple means comparison results indicated the mean slippage for the rice crop was lower (7.33%) at S1 (1.94km/h), when compared with other treatment combinations (Fig. 5). The slippage average results at 2nd and 3rd levels of ground speeds were found to be non-significant at $\alpha = 5\%$ (Fig. 5). The S1 and MC1 treatment

Table 2. Analysis of variance.

Crops	Source	DOF	Slippage (%)		Shatter losses (%)		Efficiency (%)	
			F	P	F	P	F	P
Rice	S	2	4.24	0.0310*	99.18	<0.0001*	22.18	<0.0001*
	MC	2	18.24	<0.0001*	3.16	0.0667	31.81	<0.0001*
	S x MC	4	0.44	0.7813	3.53	0.0269*	6.13	0.0027*
Wheat	S	2	16.37	<0.0001*	44.31	<0.0001*	16.48	<0.0001*
	MC	2	61.84	<0.0001*	0.17	0.8473	19.64	<0.0001*
	S x MC	4	1.08	0.3957	7.19	0.0012*	1.26	0.3224
Brassica	S	2	20.50	<0.0001*	106.32	<0.0001*	11.22	0.0007*
	MC	2	13.96	0.0002*	4.48	0.0263*	14.53	0.0002*
	S x MC	4	0.59	0.6709	3.26	0.0356*	2.15	0.1163

Significance indicated by *, significant at $p = 0.05$. Where (S) for machine speed, (MC) for moisture contents, (DOF) degree of freedom.

combination was found to be minimum % slippage for rice crop. The higher tire grip of reaper at low speed (S1) could be the reason for this low % slippage and vice versa.

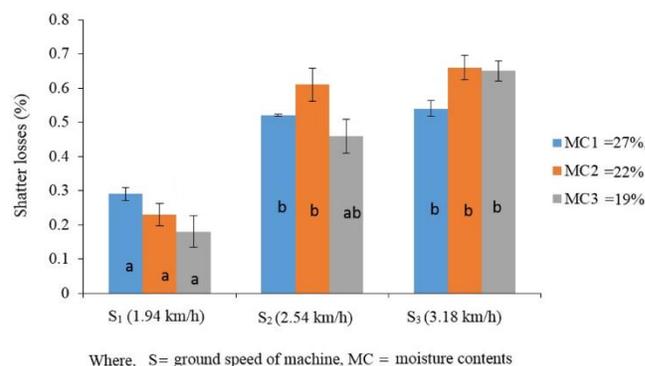


Where, S = ground speed of machine, MC = moisture contents

Figure 5. Effect of S and MC on machine slippage % in the rice field.

Likewise, for rice crop, the results revealed that the mean shatter losses were observed to be lowest (0.18%) at S1 when compared with other ground speeds (Fig. 6). The reason of high shattering losses at S2 and S3 could be due to the redundant impact implied by the reaper itself (due to high speed) on plants. Average shatter losses at three levels of speeds were found significantly different from each other @ 5% level of significance, which is suggesting that the selected levels of MC and S have an impact of shattering losses of the engine operated reaper. Same results were discussed by Alizadeh *et al.* (2007) and Singh *et al* (2008). The treatment combination of S1×MC3 was observed to give minimum shatter losses, which may be the result of less impact force of the reaper with standing stalks. These results showed that

selection of proper MC and S could enhance the picking performance of engine operated reaper. The results of LS means indicated that the reaper’s field efficiency for rice crop was found to be highest (74.22%) at combination S2×MC1, as compared to other treatment combinations (Fig. 7). There was a varying trend found for the field efficiency for different treatment combinations. The lowest field efficiency was found in the S1×MC3 combination as compared to other treatments. More crop retention time causing more losses may be the reason of lowest field efficiency at S1×MC3. The obtained results indicated that the field efficiency was influenced by MC and S of the engine operated reaper significantly.



Where, S = ground speed of machine, MC = moisture contents

Figure 6. Effect of S and MC on shatter losses % in the rice field.

The means comparison results showed that the T1 (S1×MC1) had lowest slippage % while highest field efficiency and T1

Table 3. Multiple mean comparisons of brassica and wheat crops for slippage %, shatter losses and field efficiency.

Treatment	S (km h ⁻¹)	Brassica			
		MC %	SL (%)	SP (%)	FE (%)
T1	1.94	18.32	0.270 C	07.78 C	72.930 A
T2		16.05	0.210 C	08.21 BC	70.920 B
T3		15.70	0.190 C	08.99 B	67.690 B
T4	2.54	18.32	0.500 B	08.42 B	71.77 BC
T5		16.05	0.620 A	08.93 B	69.95 BC
T6		15.70	0.460 B	09.32 AB	68.50 BC
T7	3.18	18.32	0.540 AB	09.29 AB	68.99 C
T8		16.05	0.670 A	09.25 AB	66.80 C
T9		15.70	0.620 A	10.26 A	67.51 C
			Wheat		
T1	1.94	16.70	0.240 B	09.37 C	71.460 A
T2		14.50	0.130 C	11.04 AB	69.29 AB
T3		13.90	0.110 C	11.81 AB	66.03 BC
T4	2.54	16.70	0.220 B	09.67 C	70.37 AB
T5		14.50	0.270 AB	11.8 AB	68.720 B
T6		13.90	0.270 AB	12.25 A	66.96 AB
T7	3.18	16.70	0.290 AB	10.64 B	67.19 BC
T8		14.50	0.370 A	12.75 A	65.530 C
T9		13.90	0.420 A	12.97 A	64.530 C

Where: T1 stands for treatment 1 and so on, SP = slippage, SL = shatter losses and FE = Field Efficiency. Means sharing the same letters are not significantly different at P=0.05

be considered as ideal combination of S and MC for both wheat and brassica (Table 3). While, the T8 and T9 indicated highest slippage % and lowest field efficiency, showing the very poor combination of S and MC (treatment combinations). The combination S1×MC3 (slowest speed and lowest moisture contents) gives the better crop yield and lowest slippage. Similarly, at this combination the shatter losses were observed at minimum level for wheat and brassica crops (Table 3). The reason of less shatter losses could be the slow forward speed of reaper and vice versa (Alizadeh *et al.* 2007). The more shatter losses at higher speeds may be occurred due to excessive shaking of plants. The results in Table 3 also indicated that the S (1.94 km/hr) at MC1 (18.32%) gives lowest slippage and maximum field efficiency for both wheat and brassica.

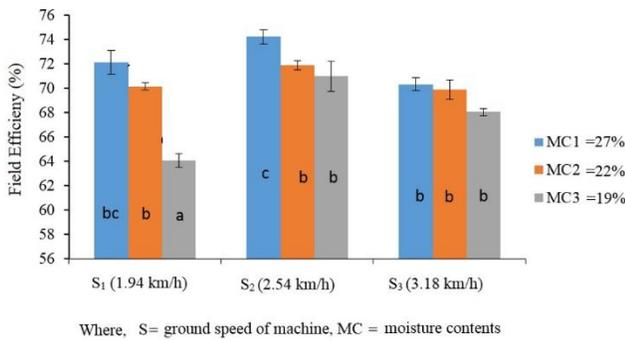


Figure 7. Effect of S and MC on field efficiency % in the rice field.

Overall, it can be concluded that S and MC individually or in combination form greatly influenced the slippage, shatter losses and field efficiency. The harvesting efficiency of engine operated reaper and profitability for small farmers can be increased by choosing appropriate S and MC.

Cost analysis of redesigned and tractor mounted reaper

Breakeven analysis focuses on the profitability of an organization or farm. Break even analysis is very important tool for organization when launching new products. The breakeven point indicates the level of operation required at which total revenue equals the total cost of production. Results of breakeven analysis indicated that this point can be achieved in 19 days (151 hours) with 8 working hours in a day (Fig.8). It is expected that a farmer can easily cross the breakeven point and earn more profit by renting the machine to other farmers. The renting cost of this reaper was considered as Rs. 1000 (\$10 @ 1US\$ = 100 PKR) per hour. The modifications in the existing reaper will also be an advantage for the farmer’s community to harvest an extra crop using the same machine. The Table.4 gives more information about different costs. The total cost of this reaper was calculated as 394.53 (Rs. h⁻¹) or (3.94 US \$ h⁻¹).

Table 4. Cost analysis of engine operated reaper.

Sr.	Particulars	Costs
1	Purchase price, P (Rs.)	120000
2	Salvage value, S (10% of P) (Rs.)	12000
3	Useful life, L (Year)	10
4	Annual use (h)	800
Fixed Cost		
1	Depreciation D= (P-S)/L (Rs. h ⁻¹)	13.50
2	Interest I= (P+S)/2 * i/L (Rs. h ⁻¹)	9.90
3	Taxes, Insurance and shelter (2% of P)(Rs.h ⁻¹)	3.00
	Total fixed cost, (Rs. h ⁻¹)	26.40
Variable cost		
1	Repair & Maintenance (@15% of P) (Rs. h ⁻¹)	22.50
2	Fuel charges (Rs. h ⁻¹), reaper used 1 liter per hour of diesel	109.25
3	Lubricant charges (Rs. h ⁻¹), @ 5% of fuel cost	16.38
4	Driver charges (Rs. h ⁻¹), an operator was charged 700 per day (10 hours of working)	70.00
5	Bundle making cost (Rs. h ⁻¹) per person	150.00
	Total variable cost (Rs. h ⁻¹)	368.13
	Total cost, fixed + variable cost (Rs. h ⁻¹)	394.53

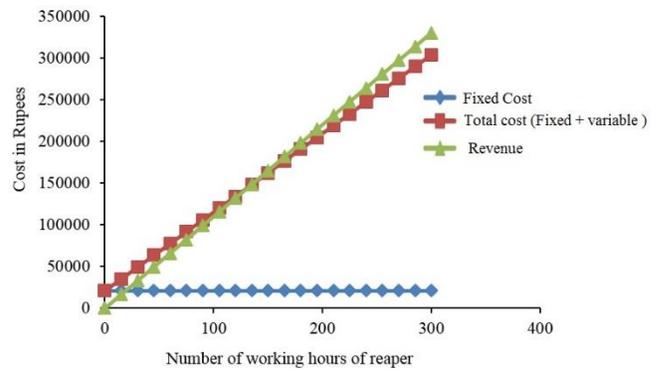


Figure 8. Break even analysis of the engine operated reaper for harvesting cereal crops.

Conclusions: The engine operated reaper was re-designed based on experimental results. Therefore, its weight is lighter, and production is more economical due to less use of raw material. The field efficiency %, slippage % and shatter losses % were affected by the varying levels of moisture contents (MC) and different ground speeds (S) of the reaper. Generally, the highest reaper ground speed results in high shatter losses, % slippage and less reducing overall field efficiency for different crops and vice versa. The breakeven point of the modified reaper can be achieved after 19 days of purchase. Overall, it can be concluded that S and MC individually or in combination form greatly influenced the slippage %, shatter losses and field efficiency. The harvesting efficiency of engine operated reaper and profitability for small farmers can be increased by choosing appropriate S and MC. Furthermore, the low cost of the engine operated reaper with an adjustable attachment will benefit farmers in

underdeveloped countries to harvest multiple crops. The economic slump in Pakistan, labor shortage and multi cropping zones will emphasize the use of such small machinery for harvesting. For the ease of farmers to assemble and disassemble, the simple nuts and bolt were used for modification of this reaper.

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