

RESEARCH ARTICLE

PERFORMANCE EVALUATION AND ECONOMIC ATTAINABILITY OF THE CHINESE WALKING TYPE SELF-PROPELLED REAPER FOR RICE HARVESTING IN NEPAL

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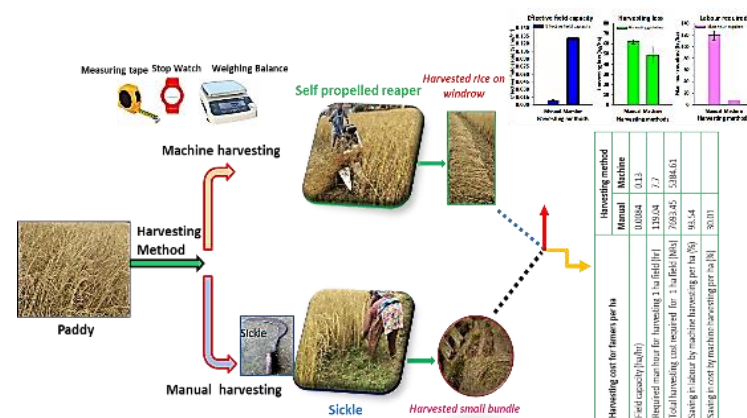
ABSTRACT

Manual harvesting (sickle), a most common practice for majority of the farm households is a labour and time intensive practices in Nepal. Therefore, there is need of harvesting mechanization option suitable for smallholder farmers to replace the manual harvesting of rice. Hence, a study was conducted to evaluate the performance of a self-propelled reaper, originally developed in China, under local farmer field condition in Lalitpur district. Reaper was evaluated in terms of different performance parameters such as field capacities, field efficiency, fuel consumption, harvesting grain loss, and associated harvesting labour and cost. The average effective field capacity of the reaper (machine harvesting) was obtained as 0.13 ha/h with a field efficiency of 68.69 % at an average operating speed and wheel slip of 1.72 km/hr and 5.46%, respectively while that of sickle harvesting (manual method) was 0.0084 ha/hr. The average fuel consumption of self-propelled reaper was obtained as 1.32 L/h. The average grain harvesting losses of 1.36% and 1.73 % were found in machine harvesting and manual harvesting. A labour saving of 93.54 % was achieved by the use of reaper (7.7 man-hr/ha) compared to manual harvesting (119.08 man-hr/ha). Manual harvesting needs almost 15.47 hours to harvest equal area as that by reaper in one hour. Likewise, cost saving of 30.01 % was occurred in custom hired machine harvesting (NRs 5384 /ha) with respect to manual method (NRs 7693/ha). Considering economic perspectives, the reaper becomes profitable only after 104.04 h of annual machine use which is equivalent to 13.6 ha of rice harvesting at a machine field capacity of 0.13 ha/hr with respect to investment cost of NRs 1, 80,000 and hiring charge at NRs 700 per hour. The benefit cost ratio (B/C ratio) was found out to be 1.77. The Payback period (PBP) was calculated to be 1.22 years. It can be concluded that small size reaper has possibility of becoming one of the suitable harvesting technology (custom hiring) for hilly and mountainous areas of Nepal where sickle harvesting is currently followed.

KEYWORDS

Economical aspects, gasoline, harvesting, performance evaluation, rice, self-propelled reaper

GRAPHICAL ABSTRACT



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1. INTRODUCTION

Rice (Nepali name: Dhan; Scientific name: *Oryza sativa* L.) is the most important food grain crop in Nepal followed by maize and wheat. Rice is grown in wide range of agro ecological zones under varying climates, altitudes and topography ranging from 60 meters in Terai to 3050 meters above sea level in Chumchure, Jumla (Bhujel, 2004). In 2018/19, it occupies total area of approximately 1.49 million ha cultivable land of Nepal with the average productivity of 3.76 t/ha producing 5.61 million tons of paddy rice (MoALD, 2020). Rice contributes about 20% of the national agricultural domestic product (AGDP) and one-third of the total calorie intake in Nepalese people. On average, Nepalese consume about 122 kg milled (or 200 kg paddy) rice per year. Cereals contribute about 90 percent of the total calorie intake, and 50 percent of this comes from rice (Khatri, 2020; Pokhrel, 1997).

Currently, agricultural labor scarcity (especially seasonal labour shortage) along with increasing labor wage is one of the blistering issues of Nepal as majority of young people are going abroad mainly gulf countries and Malaysia in search of jobs. The trend of young people migrating from villages to the cities for good job and better opportunities or leaving Nepal for foreign employment is increasing every year. As per International Organization for Migration (IOM), around 0.5 million young Nepalese (75% unskilled or low skilled labor) leave the country every year for work and currently Nepalese people are working in over 100 different countries around the world (IOM, 2019). Thus, this automatically compelled agriculture and livestock work to be the job of old people and women farmers these days.

Rice is one of the labour-intensive crops in which transplanting and harvesting operations requires more labour. In Nepal, most of the farmers harvested rice manually with the help of sickle. Sickle harvesting is very slow, tedious, drudgeries, labour-intensive and time-consuming practices as this method requires higher energy to cut the stalks and must be done by bending or sitting. Moreover, it is one of the expensive harvesting practices as it requires about 100–150-man hours to harvest one hectare of paddy field depending on the crop yield (Alizadeh and Allameh, 2013; Hossain et al., 2015). A study shows that transplanting, harvesting and threshing operation consume about 70 % of the total labour requirement for paddy cultivation in which sickle harvesting and bundle making consumes 20-25% labour (Tripathi et al., 2018; Barman et al., 2015; Debnath and Chauhan, 2020; Kumar et al., 2013; Kurhekar and Patil, 2011).

Although mechanized rice harvesting already started in flat land of Nepal, they seemed not appropriate for small land holding people considering the geographical and socioeconomic aspect either in Terai or hills. For instance, combine harvester being structurally a large, heavy and expensive machine can be used in bigger plot but it is not suitable for small, scattered and fragmented landholding of mid hills in Nepal. The maneuverability of combine harvester in hilly land is very low. Importantly, rice straw and husk are being used as feedstock for livestock animals in livestock crop integrated farming system so most of farmers do not want to lose rice straw. Combine harvester does not leave residues that can be used as feed for animals. Likewise, there are also crop residue burning issues associated with environmental pollution and soil health problems. Because of these associated environmental factors, the government of Nepal strictly banned combine harvester in 2014 and later endorsed a law banning import and custom hiring of combine harvester without baler or straw chopper in 15th March, 2015 (Basnyat, 2017; Paudel and Basnyat, 2018).

Likewise, power tiller attached reaper is also being used to harvest rice and wheat especially in Terai belt of Nepal. It is attached in front part of power tiller as additional attachments during harvesting time. However, due to additional weight (90-120 kg) in front of power tiller, there is need of additional measures in back part of tiller for counter balancing the excessive weight. There is also an issue of operational maneuverability due to requirement of more turning space for turning in harvesting field (power tiller dimension of 300*108*125 cm and reaper dimension of 145*85*60 cm). The use of this kind of reaper is not practical in narrow hilly terraces and limited to only bigger plot and flat land.

Thus, appropriate small scale mechanical harvesting options addressing those issues is prime need of Nepalese farmers. Mechanized harvesting is recognized as the most promising area of intervention to tackle increasing phenomena of labour scarcity and costs and to fuel farm prosperity and entrepreneurial opportunity in the rural part of country (Rickman et al., 2013). For instance, a group researcher reported that production cost can be minimized by the use of farm machinery since 60-65% of the total cost

of rice production belongs to labour cost alone in Nepal (Gauchan et al., 2012). Currently, there is a dearth of research information on rice mechanization options for smallholder farmer especially in the area of machine harvesting in the Nepalese context.

Focusing this, walking type self-propelled reaper could be one of the affordable rice harvesting mechanization option to tackle aforementioned problems for the small holder rural farmers of terai, mountainous and hilly belts of Nepal. Different kind of subsidies program by government bodies are being started to provide in this kind of small machines. Despite these possibilities, no any meaningful initiative has been taken on performance evaluation study of the self-propelled reaper in Nepalese context. The performance evaluation of the machine is therefore important to know its ability to harvest paddy along with techno-economic viability before any promotional work of paddy harvesting.

Thus, the objective of this study was to evaluate the field performance of Chinese self-propelled reaper machine for the harvesting of paddy. Evaluation on harvesting was done on the basis of performance parameters such as theoretical field capacity, effective field capacity, field efficiency, grain shattering loss, wheel slip and fuel consumption. Furthermore, preliminary economic viability evaluations and comparative evaluations of machine with manual harvesting (sickle) in terms of associated labour and cost were also integrated in this study.

2. MATERIALS AND METHODS

2.1 Structure, characteristics and major parts of self-propelled reaper

Self-propelled reaper is a walk behind type harvester which is operated by a 9 HP (6.6kW) gasoline engine. It is composed of three major components i.e. engine and power transmission, cutting and conveying system. The different parts and basic technical features of machine are shown in Figure 1 and Table 1. It consists of engine, frame, belt transmission system, gear box, pneumatic wheels, control lever (brake and clutch), accelerator, turning (right left) lever and reaper head. Likewise, reaper head consists of reciprocating serrated cutter bar, vertical conveyor chain with lug, row divider, spring guide, three crop row dividers with star wheels, power transmission gear box.

Table 1: Technical details and general characteristics of the Chinese self-propelled reaper

S.N	Features	Technical parameters
1.	Make & Model of machine	4G100, Chinese
2.	Reaper type	Self-propelled walking type
3.	Engine type	Engine type: 4 stroke overhead valve, forced air cooled single cylinder petrol (gasoline) inclined engine Power: 9 HP (6.7kW)
4.	Starting method	a) Manual, Recoil starting system
5.	Transmission system	a) Clutch: Wet type, friction clutch b) Gear c) No. of Gear speed: 2 Forward & 1 Reverse
6.	Model of Transmission	Gear Driven
7.	Cutting device	Reciprocating Knife bar
8.	No of cutting serrated blade	20
9.	Width of cut (cm)	100
10.	Crop Placing after cut	Right Sidewise & Banded Placed
11.	Transport wheel	a) Material Type: Pneumatic, traction b) Number of wheel: Two c) Tyre Size (cm): diameter: 40, width: 22 d) Centre to centre distance of two wheel (cm):80
12.	Reaper head dimensions (cm)	115*80*60
13.	Overall dimensions (cm)	220*115*110
14.	Fuel Tank Capacity (litre)	6

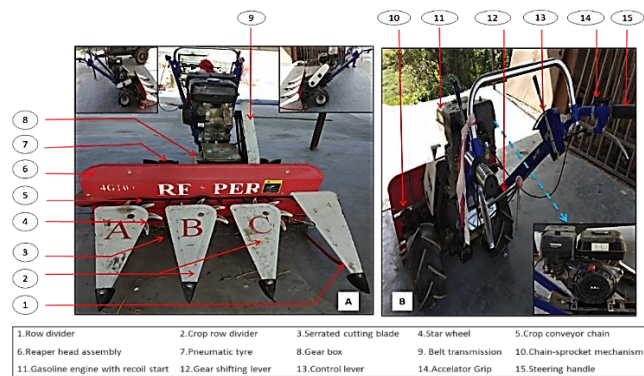


Figure 1: Photographic view of self-propelled reaper showing different parts used in this study (A-front view and side view, and B-back view)

2.2 Working principle of machine

The power generated from engine drive the reaper either forward or backward motion. During forward motion, crop row dividers divide the crop and guide to the cutter bar. After then, the reciprocating serrated cutter bar cut the crop stems by shearing action. It is held in a vertical position through star wheels and delivered to right side of the machine by lugged chain conveyors and windrows the crop on the ground uniformly perpendicular to the direction of movement of machine (Figure 1 and 2). Later, crop will be bundled manually for threshing action.

2.3 Experimental site

Field experiment was performed on a farmer's rice field at Nakkhu, Lalitpur, Nepal during October 2019. After then, rest of the analysis work was done at Agricultural Engineering Division, Nepal Agricultural Research Council, Khumaltar, Lalitpur, Nepal in October-November 2019. Geographically, experimental farm is located in the central region, Bagmati province of Nepal having latitude, longitude and average mean sea level of 27°40'N, 85°18'E and 1297masl, respectively. Rice seedling was transplanted through manual transplanting method in the studied field.



Figure 2: Photographic view of experiment on reaper harvesting and manual harvesting of paddy in farmer's field (A-Front view, B-side view, C-Rear View of reaper, and D-manual harvesting)

2.4 Experimental parameters

2.4.1 Agronomic parameters of the paddy field

The soil structure of the experimental field was clay soil. Plant height (from ground level to the upper most part of the panicle), row to row distance, hill to hill distance, plant to plant distance, plant per m² and plant per hill, were measured using measuring tape. All data were taken at three randomly selected plot and average data were taken. Hill diameter was obtained as per method described by (Nipa, 2016) using equation 1.

$$\text{Hill diameter (cm)} = \frac{\text{area of each hill (cm}^2\text{)}}{2\pi} \quad (1)$$

Moisture Content: Soil samples were put in plastic and sealed to determine moisture content. Sample was collected by using soil core samplers. Similarly, paddy and straw samples were taken and placed in sealed plastic bag to determine the moisture content of grain and straw. Grain moisture meter (Wile-78 Crusher) was used to measure moisture content of paddy grain. Briefly, Crusher was switched on using red start button and then paddy grain was selected from selection menu of crusher. 9 mL cap was filled with clean paddy and poured into the Crusher evenly. Then, Cap was screwed on until it is against the stopper resulting crushing of grain. Pressing the green (ok) button will give the moisture value of the grain. The Crusher was carefully cleaned with brush after each measurement. Likewise, the moisture content of the straw and soil (% wet basis) was determined using the conventional oven method using equation 2. Briefly, initial weight of samples were taken and then samples are normally dried for 24 hours at 100° to 105°C (212° to 221°F) in hot air oven (Accumax). Later, the final weight of samples was recorded after 24 hrs.

$$MC (\%) = \frac{(W - D)}{W} * 100 \quad (2)$$

Where,

MC is the moisture content on percentage basis,

W is initial weight of the sample before drying (wet weight in g)

D is dry weight after drying for 24 hrs in oven (g).

Physical dimensions: Vernier caliper (accuracy of ± 0.05 mm) was used to measure the dimensions of paddy rice grains. Physical dimensions (length, width and thickness) of paddy and whole rice kernel grain were determined by randomly choosing 15 whole grains using magnifying lens to read values in scale. Length to width ratio (L/W) was determined using formula 3 (Folami et al., 2016; IRRI, 1996; Khatri, 2020). Weight of paddy grain and whole grain were measured on a digital balance (SCALTEC) having minimum accuracy of 0.01g.

$$\text{Length to width ratio (LW)} = \frac{\text{Average length of paddy, mm}}{\text{Average width of paddy, mm}} \quad (3)$$

2.4.2 Machine field testing parameters

Harvesting work was carried out to determine the different machine performance parameters such as theoretical field capacity, effective field capacity, field efficiency, grain shattering loss, wheelslip, labour requirement, fuel consumption and grain yield. Cutting width, operational speed, harvesting time and the fuel consumption by reaper was recorded. Any operational limitations and difficulties were noted during the field experiment to point out constraints related to operation and handling of machine in field.

2.4.3 Machine capacity

Machine capacity was determined based on following equation

Speed: Operational speed of reaper was determined by measuring certain distance and time taken to travel this distance as per equation. Mean speed was obtained from three times replicated values.

$$\text{Operational speed (m/s)} = \frac{\text{Distance to travel (m)}}{\text{Time taken to travel (sec)}} \quad (4)$$

Theoretical Field Capacity: Theoretical field capacity was determined from forward speed and the width of cut from reaper or mean working width as per equation 5 (Alam et al., 2018; Hunt, 1995).

$$\text{Theoretical field capacity } \left(\frac{\text{ha}}{\text{h}}\right) = \frac{\text{Average speed (m/s)} * \text{cutting width of reaper (m)} * 3600}{10000} \quad (5)$$

Effective field capacity: Effective field capacity was obtained by dividing the total area harvested by total time taken to harvest that area (Hunt, 1995). Total time taken to harvest includes harvest time, turning loss time and operator rest time loss during field operation.

$$\text{Effective field capacity } \left(\frac{\text{ha}}{\text{h}}\right) = \frac{\text{Total area harvested (ha)}}{\text{Total time taken to harvest (hr)}} \quad (6)$$

Field efficiency: The ratio of effective field capacity to the theoretical field capacity will give the field efficiency in percentage (Hunt, 1995).

$$\text{Field efficiency (\%)} = \frac{\text{Effective field capacity} \left(\frac{\text{ha}}{\text{h}}\right)}{\text{Theoretical field capacity} \left(\frac{\text{ha}}{\text{h}}\right)} * 100 \quad (7)$$

2.4.4 Harvesting or grain shattering Losses

Shattering loss is the number of grains and ear heads that has fallen or remained on the ground by the shattering action of the sickle in manual harvesting, and cutter bar and conveyor of reaper during machine harvesting. In this study, we considered shattering losses as harvesting loss for both manual and machine harvesting. Briefly, losses were determined by marking an area (1m²) in harvested plot with three replications. A square frame having size of 1 m*1 m was used to mark areas. The scattered grains and heads inside the frame were collected by hand to determine the grain loss. Average rice yield per m² was calculated at harvesting time moisture content and later converted to kg/ha yield at 14% moisture content (Nipa, 2016; Wang et al., 2014). Shattering loss was determined by following equation (Nipa, 2016).

$$\text{Grain shattering loss (\%)} = \frac{\text{Grain collected after harvesting } (\frac{\text{g}}{\text{m}^2})}{\text{average rice yield @14\% MC (g/m}^2)} * 100 \quad (8)$$

2.4.5 Wheel slip measurement

Wheel slip was obtained by measuring machine forward speed with load and that without load by using equation. Briefly, 20 m distance was marked and the time taken to travel that distance with load and without load was noted down using stop watch.

$$\text{wheel slip (\%)} = 1 - \frac{\text{speed under actual field condition with load } (\frac{\text{m}}{\text{s}})}{\text{speed without load (m/s)}} * 100 \quad (9)$$

2.4.6 Fuel Consumption

The gasoline engine fuel tank was completely filled before and after finish of each harvesting work. Fuel was added by measuring on a graduated measuring cylinder and the added quantity of fuel was noted. After then, fuel consumption was calculated based on litre per hour basis.

2.4.7 Manual Harvesting of Paddy

Manual harvesting of rice was performed using traditional local sickles adopted by farmers. Harvesting depends on crop condition and plant density, the skill of the labor, sharpness of the sickle and the personal time loss of the labor. Harvesting time for both manual and machine harvesting was noted down using stop watch. The number of skilled and unskilled labour required for manual and machine harvesting was noted down.

2.5 Economic feasibility analysis of the self-propelled reaper

In our study, economic analysis was performed preliminary to know the associated financial scenario of machine harvesting compared to manual harvesting and custom hiring phenomena. It was performed based on the obtained field capacity of reaper, assumed annual working hour, paddy harvested ha per year, fixed cost and variable costs. Fixed cost includes depreciation, interest on machinery investment, insurance and taxes if any. Variable cost includes fuel, lubricants, repair, maintenance and operational costs, labour cost and miscellaneous cost which are directly related to the amount of work done by the machine. Total annual cost (NRs/yr) was the sum of fixed cost and variable cost. Salvage value of machine was assumed as 10% of the purchase price. Estimated life assumed for reaper was 8years. Repairs and maintenance cost is taken as 3% of machinery purchase cost. Fuel cost depends on fuel consumption per hectare or per hour, cost of fuel, field capacity, and working hours per year. Lubricant cost is taken as 15% of fuel cost in this study. Labour cost is obtained from number of labours used in machine and manual harvesting individually and labour rate per hour or day. Annual depreciation was calculated as per straight line method by the following equation (Alam et al., 2018; Khatri, 2020).

$$\text{Annual depreciation, } D = \frac{P-S}{L} \quad (10)$$

Where,

D= depreciation, NRs/yr

P=purchase price, NRs

S= salvage value, NRs

L=useful life of the machine, year

Interest or opportunity cost of the investment is an actual cost in agricultural machinery and was determined by straight line method by the following equation (Amponsah et al., 2017; Khatri, 2020). The interest rate is considered to be 15% of purchase value for agricultural machinery.

$$\text{Interest on investment, } I = \left(\frac{Rs}{\text{yr}} \right) = \frac{P+S}{2} * i \quad (11)$$

Where,

I= Mean interest on investment (NRs/yr)

P= Purchase value (NRs.)

S= Salvage value (NRs)

i= interest rate (%)

Tax is not considered in this study due to government policy of no taxes for agricultural machines. So, shelter and insurance cost is taken as 2% of purchase price. Total fixed cost was calculated as: Fixed cost, FC = Depreciation + Interest on investment + Tax, insurance and shelter. Total cost was calculated by adding fixed cost and variable cost. Annual fuel cost was calculated as: Annual Fuel cost: No of operating hour * price per lit (NRs) * fuel consumption (lit/hr). Based on the calculated total annual fixed cost, variable cost per hr. and assumed custom hire rate or charge per hour, the expected revenue, profit, and breakeven point were determined.

Breakeven analysis represents the area that a machine has to harvest per year in order to justify machine use by individual purchase of machine. Likewise, based on custom hiring basis, breakeven point is the intersection point between cost and income at which neither profit nor loss is incurred. It is done to know the operating cost and investment returns. It is determined by dividing the total fixed costs associated with harvesting by the custom hiring rater per hour minus the variable costs per hour. The following formula was used to estimate the BEP of the machine (Alam et al., 2018; Hunt, 1995).

$$\text{Breakeven point, } BEP = \frac{FC}{CHR-VC} \quad (12)$$

Where,

BEP = breakeven point (ha/yr or hr/yr)

FC = fixed cost (NRs/yr)

CHR = custom hire rate (NRs/hr)

VC = variable cost (NRs/hr)

Payback period: The payback period is the time taken to recover the cost of an investment and was determined by the following formula.

$$\text{Payback period, } PBR = \frac{P}{R} \quad (13)$$

Where,

PBR= Payback period (year)

P=purchase value of machine (NRs)

R=profit per year in NRs

Internal rate of return (IRR): The rate of return that makes the net present value of all cash flows (both positive and negative) equal to zero for an investment is termed as IRR. IRR is calculated based on the following equation (Khatri, 2020; McCamish, 2020).

$$P_0 + \frac{P_1}{(1+IRR)} + \frac{P_2}{(1+IRR)^2} + \frac{P_3}{(1+IRR)^3} + \dots + \frac{P_n}{(1+IRR)^n} = 0(NPV) \quad (14)$$

Where:

- P₀= Initial investment (cash outflow)
- P₁, P₂, P₃= Cash flows in periods 1, 2, 3, n etc.
- IRR = Internal rate of return
- NPV = Net Present Value
- N = Assumed economic life of the machine (years)

2.6 Data analysis

All analyses and measurements are displayed as average values of triplicate readings. Descriptive analysis was done to summarize data into averages, standard deviations, and standard error values by statistical tool using MS Excel. All inferential analysis and graph was done using Sigma Plot software version 12.5 (Systat Software Inc, USA).

3. RESULTS AND DISCUSSION

3.1 Physical and agronomic properties of paddy and paddy field

Moisture content of paddy, soil and rice straw were $23.23 \pm 0.46\%$, $17.7 \pm 1.49\%$ and $13 \pm 2.37\%$, respectively during field experimental time. At moisture content of 14%, the average grain length, width and thickness of paddy were 8.93 ± 0.63 mm, 2.42 ± 0.23 mm and 1.80 ± 0.19 mm, respectively while that of whole kernel after husk removal were 6.54 ± 0.46 mm, 2.08 ± 0.20 mm and 1.63 ± 0.15 mm, respectively ($n=15$). Length/width ratio of paddy and whole kernel were 3.69 and 3.14, respectively (Table 2). Shape of grain can be determined from length, width, and L/W ratio. Based on the standards of IRRI, the rice grain of this experiment was classified as slender grain because calculated L/W value lies within range of slender class (L/W ratio: over 3.0) (IRRI, 1996; Khatri, 2020).

Agronomic parameters such as row spacing, hill spacing, plant height, number of plants per m^2 area, number of hills per m^2 , number of plants per hill, hill diameter for the paddy is summarized in Table 2. From the Table 2, it can be seen that variation in obtained row spacing (14-25 cm) and hill spacing (10-18 cm) could be due to manual transplanting of rice. The average plant height of the rice was 123 ± 1 cm with the range of maximum-minimum values of 122-124 cm. Similarly, the average number of hills per m^2 and number of plant per hill were 55 ± 4.08 and 10 ± 1.92 ranging from 50-60 and 7-12, respectively (Table 2). The average weight of the rice grain per m^2 was 360 ± 15 g at 23.3% moisture content. The achieved average grain yield per m^2 of experimental paddy field was later converted to kg/ha at 14% moisture content which is 3223.26 ± 134.30 kg/ha (Table 2).

Parameters	Mean	Maximum	Minimum
Date of paddy planting	2019/06/28	-	-
Date of Harvesting	2019/11/08	-	-
Row spacing (cm)	18.5 ± 4.04	25	14
Hill spacing (cm)	14.27 ± 2.87	18	10
Plant height (cm)	123 ± 1	124	122
No of plant per m^2	336 ± 30	371	319
No of hills per m^2	55 ± 4.08	60	50
No of plant per hill	10 ± 1.92	12	7
Hill diameter (cm)	2.65 ± 1.28	3.98	1.43
Grain moisture content (%)	23.23 ± 0.46	23.5	22.7
Straw moisture content (% w.b)	13 ± 2.37	14.5	10.4
Physical dimensions (n=15)			
a) Grain length (mm)	8.93 ± 0.63	10	8.1
b) Grain width (mm)	2.42 ± 0.23	2.7	2
c) Grain thickness (mm)	1.80 ± 0.19	2.2	1.5
L/W ratio	3.69	4.40	3.0

All values are expressed as means \pm standard deviation of triplicate readings

3.2 Performance evaluation of self-propelled reaper

3.2.1 Field capacity

Figure 3 and Table 3 showed the different performance indices of machine harvesting. The results showed that the theoretical field capacity of self-propelled reaper was 0.18 ha/hr. The effective field capacity of the self-propelled reaper was 0.13 ha/hr at an average operating speed of 1.72 km/hr which is 14.47 times higher compared to sickle harvesting (0.0084 ha/hr). Furthermore, average harvest time, turning loss time, and break time was 21.87 ± 0.48 , 5.17 ± 0.42 and 4.5 ± 0.58 minutes, respectively which resulted a total time of 31.54 ± 0.75 minutes for harvesting 660 m^2 area (7.97 ± 0.19 hr per ha) by reaper. Previous studies on the evaluation of

different types of self-propelled reaper by different researcher reported varied field capacities. For instance, a study by some researchers reported that the average field capacity of Korean self-propelled reaper, China self-propelled reaper and BRRI reaper was 0.18, 0.17 and 0.15 ha/h, respectively (Alam et al., 2018)

Similarly, a research obtained field capacity of 0.15 and 0.23 ha/h for Korean and Vietnam self-propelled reaper having cutting width of 1.2m (Nipa, 2016). A group researcher performed a comparative study of reaper and manual harvesting of rice (Alizadeh et al., 2007). From their studies, the obtained field capacity of machine harvesting (0.17ha/h) was 21 times higher than manual method (0.008ha/h). The obtained values in those studies were higher than this study. In contrary, a group researcher reported a field efficiency of 0.105ha/hr and 0.0045 ha/hr for reaper and manual harvesting which is lower than the values obtained in this study (Vora et al., 2015). The variations in the effective field capacities could be due to varied cutting width (1.2m) than reaper of this study (1m) as well as different crop type and density, operator's skill, variations in the operating speed, time losses and soil condition.

3.2.2 Field efficiency

The obtained field efficiency of self-propelled reaper in this study was $68.69 \pm 1.64\%$ with maximum-minimum value of 70.62-67.30%. A study reported a field efficiency of 55% and 68% for 1.2 m working width Korean and Chinese self-propelled reaper during rice harvesting (Alam et al., 2018). Likewise, a study obtained field efficiency of 50% and 64% for Korean and Vietnam self-propelled reapers during rice harvesting (Nipa, 2016). Likewise, field efficiency of 58.39% was mentioned during their comparative study of paddy harvesting (Vora et al., 2015). The variation in the field efficiency could be due to the different agronomic characteristics of rice, machine speed, time losses and operator's skill (Alizadeh and Allameh, 2013).

Parameters	Mean	Maximum	Minimum
Average theoretical Speed (m/s)	0.51 ± 0.00	-	-
Average operational speed (m/s)	0.48 ± 0.01	0.49	0.47
Machine harvested area (m^2)	660 ± 0	-	-
Total time taken (min)	31.54 ± 0.75	32.18	30.66
Theoretical field capacity (ha/hr)	0.18 ± 0	-	-
Effective field capacity (ha/hr)	0.13 ± 0.01	0.13	0.12
Field efficiency (%)	68.69 ± 1.64	70.62	67.30
Wheel slip (%)	5.46 ± 2.05	8.12	3.84
Left over straw height in ground after machine operation (cm)	2.5 ± 0.41	3	2
Grain weight per m^2 at 23.22% MC (g)	360 ± 15	375	345
Grain yield at 14% MC (kg/ha)	3223.26 ± 134.30	3357.56	3088.95
Grain shattering loss (%)	1.36 ± 0.28	1.68	1.20
Fuel consumption (L/hr)	1.32 ± 0.09	1.44	1.24

All values are expressed as means \pm standard deviation of triplicate readings

3.2.3 Harvesting loss

Shattering loss is considered as harvesting loss in this study. The grain losses for manual and machine harvesting are revealed in Figure 3. From the Figure 3 and Table 3, shattering loss of machine (48.73 ± 8.08 kg/ha) and manual harvesting (62.1 ± 2.07 kg/ha) were $1.36 \pm 0.28\%$ and $1.73 \pm 0.02\%$, respectively of total yield per ha at average machine forward speed and paddy moisture content of 0.48 m/s and 23.23%. Harvesting loss was 27.49% higher in manual harvesting than that of machine harvesting. A group researcher obtained the grain losses of 1.40%, 1.66% and 1.50%, for manual and mechanical harvesting (Korean and Chinese model), respectively (Alam et al., 2018). Similarly, a researcher mentioned shattering losses ranges from 0.43-1.04% in machine harvesting (Nipa,

2016). In a similar study, machine and manual harvesting losses for rice were found 2.46% and 8.01 % respectively (Rahman et al., 2004). The grain losses obtained in this study was less than the value of 3.95% which was obtained when mechanically harvested at moisture content higher than normal limit of 23–27% (Kurhekar and Patil, 2011). It could be concluded that harvesting loss depends on the soil condition, agronomic characteristics of the paddy, harvesting speed, time and operator's skill.

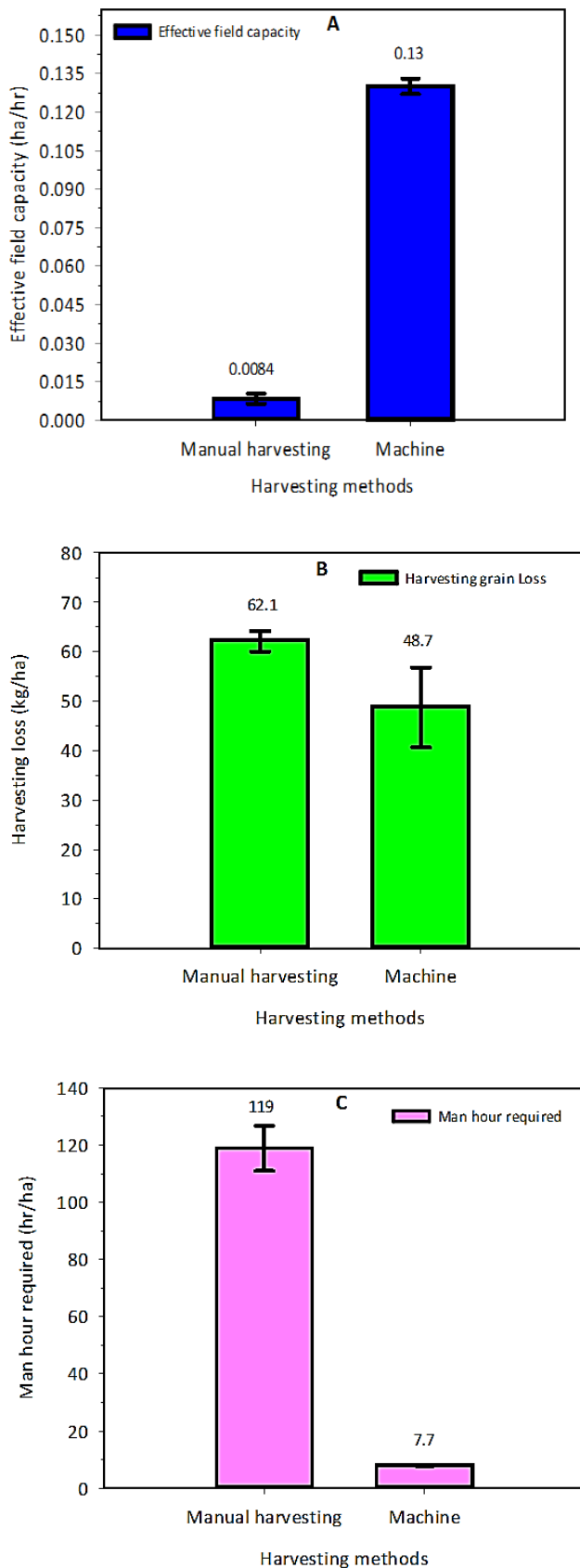


Figure 3: Average field capacity (A), Harvesting grain loss (B) and Labour required (C) of manual and machine harvesting

3.2.4 Fuel consumption and wheel slip

Fuel consumption of reaper was found to be 1.32 ± 0.09 L/h at an average operating speed of 1.72 km/hr in this study. Fuel consumption depends on operator's skill, engine power and crop density. Likewise, average wheel slip of $5.46 \pm 2.05\%$ with maximum-minimum value of 8.12-3.84% was obtained.

3.3 Economic evaluation of machine harvesting versus manual harvesting

3.3.1 Labour and cost saving by machine harvesting compared to manual harvesting

In order to make rough preliminary economic considerations based on farmers perspective, we compared the added value related to labour saving in machine harvesting relative to manual harvesting. During computation, the achieved harvesting time of the discussed experiment were extrapolated to man hour required per ha. Table 4 showed the labour required to harvest one hectare by manual method as compared with respect to machine harvesting (on the basis of custom hiring). The labour requirement for machine harvesting by the self-propelled reaper was 7.7 man-hr/ha and that by manual harvesting was 119.08 man-hr/ha in this study. A labour saving of 93.54 % was achieved by the use of reaper (Table 4).

From the Table 4, it can be said that manual harvesting need almost 15.47 hours to harvest equal area as that by reaper in one hour. One labour can harvest 0.0084 ha rice per hour by hand but he can harvest 0.13 ha rice per hour by machine which resembles 14.47 times more area than manual harvesting. Labour requirement due to machine harvesting was much lower than that of manual harvesting. Likewise, harvesting cost of rice by machine and manual harvesting were NRs 5384 /ha and NRs 7693/ha, respectively. A cost saving of 30.01 % was occurred in custom hired machine harvesting with respect to manual method (Table 4). Besides cost and labor saving from machine harvesting, farmers can harvest the field and plant next crop in time.

Table 4: Labour and cost requirement between manual and machine harvesting in this study

Harvesting cost for famers per ha	Harvesting method	
	manual harvesting	Machine harvesting
Field capacity (ha/hr)	0.0084	0.13
Required man hour for harvesting 1 ha field(hr)	119.04	7.7
Total harvesting cost required for 1 ha field (NRs)	7693.45	5384.61
Saving in labour by machine harvesting per ha (%)	93.54	
Saving in cost by machine harvesting per ha (%)	30.01	

Daily minimum wage rate for unskilled worker=NRs 517

Custom hire rate for reaper=NRs 700/hr

The assumed working time: 8 hr per day

The cost of manual harvesting is NRs 7693.45 per ha and variable cost of machine per ha is NRs 2390.23 (harvesting area of 62.4 ha per year) and fixed cost per year is NRs 40500 (Table 4 and 5). So based on these values, the minimum justifiable harvesting area for individual ownership of reaper is 7.63 ha. Rice harvesting by individual ownership of machine will be beneficial to the farmers when the annual use exceeds 7.63 ha of land. Operating cost per hectare was decreased as the area harvested increased. In Nepal, it is not economically justifiable to purchase all machines from tillage to harvesting by each individual farmer for his sole farm activities only as average size of land holding is less than 0.5 hectares per household. This has severely limited application of mechanization technologies in Nepal. Thus, custom hiring method is appropriate way for the adoption of expensive machinery in Nepalese farm.

3.3.2 Economical aspects of reaper on the basis of custom hiring

An economic analysis of reaper using relevant cost assumptions was performed and shown in Table 5. As per table, the total fixed cost was NRs 40500 per year and total variable cost per year was NRs 149150.4 giving

a total cost of reaper operation as NRs 395.10 per hour at an estimated annual working hour of 480. Total cost of harvesting per ha is NRs 3039.26 and assumed machine harvesting charge (custom hire rate) is NRs 700 per hour. The estimated profit is about NRs 2680.10 per ha charging a harvesting fee of NRs 700/hr. This resulted annual net income of NRs 146349.6 for a total annual harvesting capacity of 62.4 ha by the reaper with annual machine use of 480 hr. Break even analysis conducted with respect to annual use of machine and total annual cost or total revenue was shown in Table 5 and Figure 4. As per figure 4, both the total annual cost and total revenue increased with increasing hour of machine use. It can be seen that at 104.04 hour of machine use, total annual cost line intersected with annual revenue lines showing the breakeven point.

The breakeven point at 104.04 hour of machine resembles 13.53ha rice harvested area at a machine field capacity of 0.13 ha/hr. Thus, cost analysis showed that the breakpoint of the machine harvesting was 13.53 ha per year based on 480 hours usages of the reaper per year which indicated annual use below 13.53 ha for rice was not economically beneficial to harvest by reaper. The area between the total cost and revenue above the 104.04hour of machine use point is the potential annual profit that can be accrued from reaper. From the analysis of economic data, the estimated payback period is 1.22 years with respect to annual net income, harvesting output, annual machine use and per hour hiring charge of NRs 146349.6, 62.4ha, 480hr and NRs 700, respectively. Increasing annual machine hour to more than 480 will reduce payback period. The internal rate of return and B/C ratio achieved from the investment were 80.63% and 1.77. From the economic analysis, it can be revealed that custom hiring of reaper could be one of the feasible options to use in small, fragmented and scattered plots of individual farmer to address the problem of agricultural labour scarcity.

Farmers who have reapers can provide harvesting service to other farms in their farming community. The major operational constraints observed in the use of reaper were need of manual harvesting in border side of field for easy turning and avoiding more harvesting losses and difficulty to harvest lodged paddy as shown in Figure 5. Sometime, paddy stem choking in reaper head was occurred due to non-uniform spacing of paddy bunch (manually transplanted field) and lodged paddy. Thus, manual harvesting is recommended in that kind of lodged paddy field. Similarly, skilled labour is needed to have maximum efficiency and reduce associated harvesting losses and cost. Likewise, uncertainty on availability of spare parts and repair facilities are the infrastructural constraints.

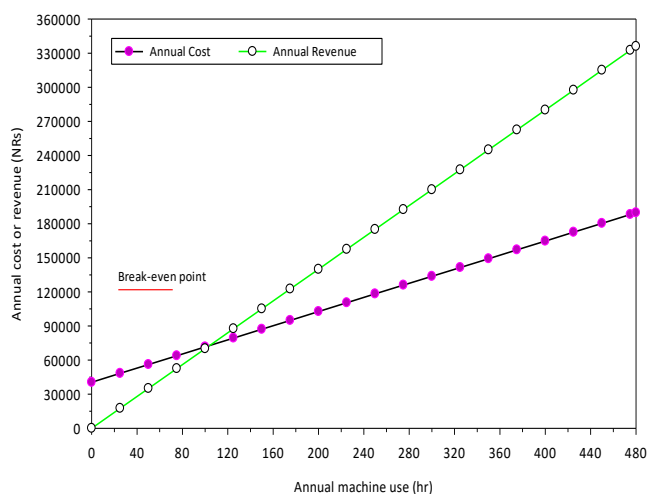


Figure 4: Breakeven point of reaper use



Figure 5: Lodged paddy field

Table 5: Results of the economic analysis of the self-propelled reaper

Parameters	Self-propelled reaper
Initial cost of machine (NRs)	180000
Assumed economic life of the machine (years)	8
Salvage value @ 10% of machine price (NRs)	18000
Fixed cost (NRs/yr)	
Annual depreciation value (NRs)	20250
Annual interest on investment@ 15% (NRs)	14850
Shelter and insurance @ 3% of machine price (NRs)	5400
Total fixed cost	40500
Variable cost	
Annual machine run time (hr/yr)	480
Fuel cost (NRs)	69696
Lubricant cost (15% of fuel) (NRs)	10454.4
Annual repair and maintenance cost @5% of purchase price(NRs)	9000
Annual labour cost (NRs)	60000
Annual variable cost (NRs)	149150.4
Variable cost per hour (NRs)	310.730
Total annual cost (NRs)	189650.4
Total operating cost per hour (NRs/hr)	395.105
Machine field capacity (ha/h)	0.13
Annual total harvesting capacity (ha/yr)	62.4
Cost per ha (NRs)	3039.269
Custom hire rate/price per hour (NRs)	700
Total revenue per year from harvesting (NRs)	336000
Total revenue per ha (NRs)	5384.615
Net revenue/margin(NRs/ha)	2345.3
Net income(NRs/yr)	146349.6
Gross margin (NRs/ha)	2994.38
Benefit cost ratio	1.77
Payback period (year)	1.22
Internal rate of return (%)	80.63
BEP point (hr)	104.04

^aUsing One dollar is equivalent to 113.85 NRs, the price of 1 lit petrol in Nepal is equals to 110 Nepalese rupees (NRB, 2020)

Daily minimum wage rate for skilled worker= NRs 890-1200, Avg. NRs 1000.

Daily minimum wage rate for unskilled worker=NRs 517,.....(MOL, 2018).One skilled labour is used for reaper operation.

The assumed annual operating time: 8 hr per day, 30days in each month and 2 month per year considering rice harvesting season is two-month period

BEP: Breakeven point

4. CONCLUSION

- The self-propelled reaper has an effective field capacity of 0.13ha/hr with a field efficiency of 68.69% at an average operating speed, wheel slip, paddy moisture content and soil moisture content of 1.72 km/hr, 5.46%, 23.23% and 17.7%, respectively.

- Harvesting loss was 27.49% higher in manual harvesting than that of machine harvesting.
- The use of a self-propelled reaper machine saves more than two third the labor required for rice harvesting by manual method.
- Self-propelled reaper (custom hiring method) shortened the harvesting cost (30.01% lesser) compared to manual harvesting.
- Considering economic perspectives, the reaper becomes profitable only after 104.04 h of annual machine use which is equivalent to 13.36 ha of rice harvesting at a machine field capacity of 0.13 ha/hr with respect to investment cost of NRs1,80,000 and harvesting charge at NRs 700 per hr. The estimated (B/C ratio), IRR and payback period were 1.77, 80.63% and 1.22years.

Overall, from our findings, we suggest that reaper could be one of the beneficial and efficient options for reducing the production and labour cost and improving labour efficiency in harvesting task without increasing the grain losses with respect to manual harvesting. The reaper can be used by farmers' cooperatives and local entrepreneurs that are interested to engage in custom hiring business that will provide additional business opportunities in the rural areas. However, further investigation of the reaper under a wide range of operating speed, crop density and soil conditions across different agro-ecological zones and economic comparison with manual harvesting in long term mode is recommended. It is also recommended to perform evaluation study on harvesting of wheat to have its maximum use per year and increase profitability. Importantly, there are still sustainability challenges of timely availability of spare parts and, repair and maintenance service of the reaper in farm level by the authorized bodies.

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