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Performance optimization and knife dynamics of power tiller operated reaper during wheat harvesting

Muhammad Yamin[1], Shanawar Hamid[2,3], Muhammad Azhar Ali[1,*], Sajjad Bashir[1], Mazhar Iqbal[4] and Muhammad Ashraf[5]

[1]Faculty of Agricultural Engineering & Technology, University of Agriculture, Faisalabad (38040) Pakistan; [2]Departemnt of Agricultural Engineering, Faculty of Engineering & Technology, Khwaja Fareed University of Engineering and Information Technology, Rahim Yar Khan, Pakistan;[3]Additional Director, Office of Research, Innovation and Commercialization (ORIC), University of Narowal, Pakistan;[4]Sub-Campus Burewala, University of Agriculture, Faisalabad, Pakistan;[5]Agricultural Engineering Research Division, Faisalabad, Government of Punjab, Pakistan
*Corresponding author's e-mail: azhar_ali@uaf.edu.pk

Mechanized harvesting is one of the components of agricultural mechanization used to overcome grain losses and enhance the production compared to the conventional harvesting. Power tiller operated reapers are quite effective for harvesting practices in small fields and especially in mountainous regions where the crops are grown on terraces. Compared to the tractor mount reaper and combine harvester, it saves fuel and cuts the maximum straw to produce the fodder of almost 4000 kg ha^{-1} after the threshing operation. Thus, in case of wheat crop, it helps to save a significant energy of 1,524,000 kcal ha^{-1} avoiding the environmental pollution by infield burn of the straw. However, un-optimized use of power tiller operated reaper may result in high maintenance cost, low efficiency and distress among the small land holding farmers. The main objective of this study was to quantify the optimum cutting knife dynamics by optimizing the performance parameters of power tiller operated reaper like cutting speed, operating speed, cutting index, field capacity and fuel consumption. A combination of forward speed at 2.82 km h^{-1} and cutting speed at 3.42 km h^{-1} with cutting index of 1.21 was found to be most effective for a minimum grain harvesting loss of 101.33±1.0 kg ha^{-1} at a fuel consumption of 6.27±0.030 L ha^{-1}. A higher field efficiency of 71% was also recorded at cutting index of 1.21 for the same combination of forward and cutting speeds. Locus of cutter bar knife for the optimum combination of forward and cutting speeds helped to examine the operation of crank and cutter bar, prolonging the life of cutting mechanism. Thus, optimized performance of power tiller operated reaper will help to attain higher field efficiency at low fuel consumption and low maintenance.
Keywords: Mechanized harvesting; power tiller; reaper; cutter bar; cutting speed; field capacity.

INTRODUCTION

Agricultural mechanization is an explicit application of the mechanical assistance to enhance the productivity of crops for food with less labor. Mechanized farming is one of the best inputs to get better yield and the protection of the cereal crops (Mandal *et al.*, 2015). Though mechanized farming can enhance the production of crops, it should be timely planned keeping in view the other inputs (Yamin *et al.*, 2022; Tiwari and Gite, 2002). The level of mechanized farming in agriculture differs with different operations. Yet it is merely 50% for developing countries, as compared to 90% in developed countries. The maximum level of mechanization (60-70%) was spotted in harvesting and threshing actions by Alam (2006).

Harvesting is an important farming operation. This is the era of intensive agriculture which requires immediate sowing of another crop after harvesting one. There is a threat of shattering losses if harvesting is delayed at crop maturity. The harvesting losses with normal harvesting operations are amplified linearly with respect to time, ranging from 3% in the first week of operation to 7% in the third week very after maturing of crop (Khan *et al.*, 2003).

Mechanized harvesting is used to overcome grain losses and to enhance the production, field capacity and cost efficiency as compared to the conventional manual harvesting. Harvesting machines include; tractor mounted reapers, power tiller operated reapers and combine harvesters. The field efficiency of these machines varies from 65% to 85%, according to the field conditions, environmental conditions

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and operator's skill (Shamshiri *et al.*, 2013). Power tiller operated and tractor front mounted reaper save 45-60% labor and cost of harvesting by 60-70% compared to the manual harvesting. Therefore, the demand of harvesting machinery has tremendously increased (Alam *et al.*, 2017; Ismail and Abdel-Mageed, 2010).

Selection of proper harvesting machinery depends on the performance of machinery, field conditions, affordability, and the time limitations (Shamshiri and Ismail, 2013). The performance of harvesting machinery depends on cutting speed, forward speed, field capacity and field efficiency (Shamshiri *et al.*, 2013). During harvesting, cutting speed of any mechanical implement is a major factor to affect the harvesting efficiency of that implement. The cutting speed must be optimized as it affects grain loss. By increasing the cutting speed, the grain loss increases due to shattering of grains (Douthwaite *et al.*, 1993).

According to Kurhekar and Patil (2011), the forward speed of a harvesting implement is another factor which plays an important field operation. Combine harvester and tractor mounted reaper can be operated at higher operating speeds as compared to other equipment (e.g., power tiller operated reaper) that results in enhanced field capacity. With respect to operating speeds, combine harvester and tractor mounted reapers consume more fuel than the self-propelled power reapers which work on low operating speeds and hence consume less fuel (Mandal *et al.*, 2013).

In Pakistan, combine harvesters are being used by the farmers with large land holdings, but majority of the farmers have small land holding using straw as a fodder for the livestock (Yamin *et al.*, 2011). Combine harvester leaves the whole straw in the field which increases the cost of subsequent tillage operations as it requires more energy for the operation. Therefore, farmers avoid the higher cost of tillage and burn the straw. This practice results in increased environmental pollution, wastage of energy and reduction in economic value of straw as fodder and the source of organic matter. Thus, the burning of the straw takes part in global warming as temperature rises and produces hazardous gases like CO_2 (70%), CO (7 %), NO_x (20 %), N_2O (2.1 %) and SO_x (17 %). On the other hand, tractor mounted and power tiller operated reapers cut the maximum straw and produces almost 4000 kg of fodder per hectare after the process of threshing which costs around 373 USD ha^{-1}. In this way, reapers help to save a significant energy of 1,524,000 kcal ha^{-1} avoiding the environmental pollution produced due to the infield burn of straws (Ramulu and Deepshika, 2018).

Although, field capacity is high and grain loss percentage is lower in case of combine harvester as it can harvest crops in comparatively high moisture content, but its bigger size, high initial cost and more fuel consumption limit its use in small fields. The field operation of tractor mounted reapers is also expensive because tractor has a higher initial price and more fuel consumption as compared to the power tiller operated reapers (Chaab *et al.*, 2020; Kumar *et al.*, 2018; Jun *et al.*, 2016). However, Power tiller operated reaper is a good alternate which can be used effectively for harvesting practices in small fields and mountainous areas where the crop is grown mostly in terraces (Shreen *et al.*, 2016).

With respect to performance in the small fields, initial and operating costs, the power tiller operated reaper is quite affordable as compared to combine harvester and tractor mounted reaper. Comparing to the manual harvesting, power tiller operated reaper is far more effective to avoid the high harvesting cost and delays in harvesting due to the shortage of labor and slow manual operation (Omran, 2008). However, un-optimized use of small scale farm machinery may result in high maintenance cost and low efficiency. Thus, it is much important to optimize such farm machinery according to the local conditions and human resource. The aim of this research is to optimize the performance of power tiller operated reaper by quantifying the optimum cutting knife dynamics on the basis of performance parameters like cutting speed, operating speed, cutting index, field capacity and fuel consumption.

MATERIAL AND METHODS

***Description of power tiller operated reaper*:** A power tiller operated reaper of 960 cm width with stroke length of 76 cm and knife length of 11.43 cm was assembled in Tyeba Industries, Faisalabad, Pakistan (Figure 1). Power tiller uses the diesel engine of 6.71 kW.

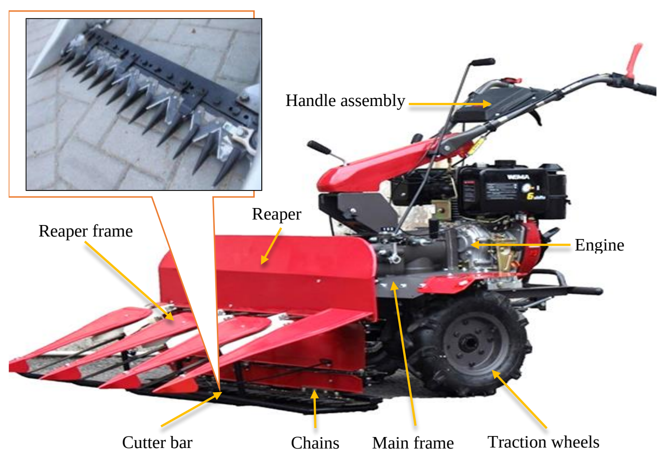

Figure 1. Power tiller operated reaper

Field testing of power tiller operated reaper: Performance optimization of power tiller operated reaper involves the testing of machine based on forward speed, cutting speed and cutting index for computing minimum grain loss and fuel consumption. It also includes the determination of field capacity and field efficiency. Before testing the power tiller operated reaper in the field, pre-harvest loss was recorded by placing the steel bar frame of 1 m^2 randomly at eight different places in the field. Dropped tiller and grains were collected inside the frame and weight of collected grains was recorded as a pre-harvest loss. This pre-harvest loss was excluded from the total grain loss to compute the actual harvesting loss. Tsegaye et al. (2017), Bala et al. (2010) and McMaster et al. (2000) mentioned the same way of measuring the harvesting loss.

Forward and cutting speeds of machine: There is a significant effect of forward speed of machine on grain loss and fuel consumption. When forward speed increases, both grain loss and fuel consumption increase and vice a versa. Forward was calculated using the equation (1) described by Tsegaye et al. (2017) and Prabhakar and Janardan (2000).

$$O_S = \frac{3.6d}{t} \quad (1)$$

Where, O_S = operating speed, km h^{-1}; d = distance of travel, m; t = time for harvesting in seconds.

Inclusive of machine's forward speed, grain loss also depends upon the cutting speed and the proper registering of cutter bar knife (Figure 2 A, B) while cutting speed is affected by the crank speed and length of stroke (Figure 2 B). Length of stroke is constant while crank speed is variable and can be adjusted from accelerator of tiller engine. Cutting speed increases when speed of operating crank increases (Figure 2 C). Noby *et al.* (2018) and Prakash *et al.* (2015) evaluated the cutting speed on the same principle using the equation (2) given below.

$$C.S = \frac{LN}{30} \quad (2)$$

Where, C.S = cutting speed (m/s), L = length of stroke (m), N = crank speed (rpm)

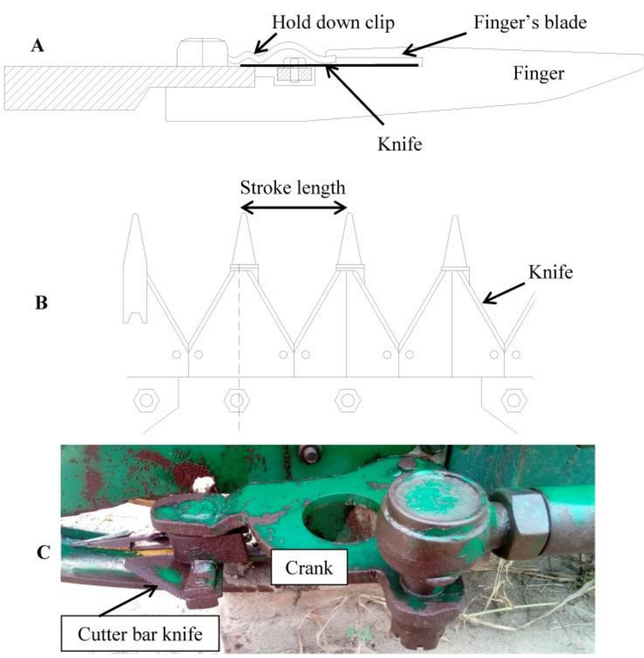

Figure 2. Registering of cutter bar knife before field operation

Cutting index: Cutting index is calculated by taking the ratio of cutting speed to the forward speed of machine (Equation 3). Cutting index plays a significant role in the cutting efficiency of the reaper. It is an index to describe the harvesting performance of the reaper. Noby et al. (2018) evaluated the cutting index by taking ratio of cutting speed to operating speed.

$$C.I = \frac{C.S}{Os} \quad (3)$$

Where, C.I = cutting index, C.S = cutting speed, O.S = operating speed

Theoretical field capacity, effective field capacity and field efficiency: Theoretical field capacity depends upon cutting width and operating speed of the machine. Both cutting width and operating speed has significant effect on theoretical field capacity. Cutting width of a machine is constant but operating speed can be changed according to need. By increasing operating speed, theoretical field capacity increases. Tabatabaekoloor (2010) and Rahman et al. (2004) worked on different self-propelled power reapers and calculated the theoretical field capacity using equation 4.

$$FC_t = \frac{Cw \times Os}{10} \quad (4)$$

Where, FC_T = theoretical field capacity (ha h^{-1}), CW = cutting width (m), OS = operating speed (km h^{-1})

Effective field capacity represents the area covered in unit time which is always lower than theoretical field capacity due to the turning over, crossing of hurdles and refueling of the fuel tank which takes times. Kumar *et al.* (2018) and Bagheri *et al.* (2008) worked on different harvesting machines and evaluated the effective field capacities with the equation 5.

$$FC_A = \frac{A_c}{T_t} \quad (5)$$

Where, FC_A = actual field capacity (ha h^{-1}), A_c = area covered during test (ha), T_t = total time (h)

Field efficiency is the percentage ratio of effective field capacity to the theoretical field capacity as shown in equation 6 (Gajakosvivek *et al.*, 2013; Singh, 2005). Field efficiency is higher if the difference between actual and theoretical field capacity is minimum.

$$F.E = \frac{FC_A}{FC_T} \times 100 \quad (6)$$

Where, F.E = field efficiency, FC_A = actual field capacity, FC_T = theoretical field capacity

Statistical experiment: Grain loss and fuel consumption were recorded by employing three commonly adapted forward (2.01, 2.82, 3.33 km h^{-1}) and two cutting speeds (3.42, 4.53 km h^{-1}) of the machine during the harvesting operation (Figure 3). The purpose of employing three and two cutting speeds was to expose the speeds which give grain loss and fuel consumption at their minimum level. At each forward speed three replications were taken for grain loss and fuel consumption. Thus a 3×2×3 factors factorial experiment was planned under complete randomized design (CRD) and data were analyzed using Statistix v9.

Figure 3. Performing the harvesting operation in the field.

Knife dynamics: During the operation of the cutter bar, the knife edges not only perform reciprocating movements but simultaneously travel with the machine ahead. Thus the cutter bar performs harmonic oscillations in its relative displacement as well as a translatory motion at constant speed, that is

$$L = vt \qquad (7)$$

Where, L = forward distance of machine (m), v = forward speed of the machine (m/s), t = time to cover the distance "L" (m)

During rotation of the crank through 180° ($\pi = \omega t$) the cutter knife moves from the extreme left to the extreme right position, the machine moves through a distance 'L' along the Y-axis (Equation 8 to 11). Finally, equation 12 gives the velocity of cutter bar based on the revolutions of operating crank.

Thus

$$L = vt = v\,(\pi/\omega) \qquad (8)$$

$$v = \omega L/\pi \qquad (9)$$

Since

$$\omega = 2\pi N/60 \qquad (10)$$

Therefore,

$$L = v\pi 60/2\pi N \qquad (11)$$

and

$$v = LN/30 \qquad (12)$$

Where, ω = angular velocity of crank (rad), N = No. of revolutions of crank (rpm)

RESULTS

***Performance evaluation of power tiller operated reaper*:** Statistical analysis revealed that forward speeds of machine have significant effect on harvesting loss and fuel consumption while cutting speed has not contributed significantly in lowering the grain harvesting loss and fuel consumption. Table 1 shows the effect of cutting speed and forward speed on harvesting losses. In first trial, at 3.42 km h^{-1} fixed cutting speed, three forward speeds (i.e., 2.01, 2.82 and 3.33 km h^{-1}) were evaluated. The result shows that grain losses were 109.33 kg ha^{-1} at 2.01 km h^{-1}, 101.33 kg ha^{-1} at 2.82 km h^{-1} and 113.33 kg ha^{-1} at 3.33 km h^{-1} forward speed. The best forward speed of machine was 2.82 km h^{-1} which gave the minimum harvesting loss (i.e., 101.82±1.0 kg ha^{-1}). Similarly, at 4.53 fixed cutting speed, the grain losses were 110.67 at 2.01 km h^{-1}, 102.30 kg ha^{-1} at 2.82 km h^{-1} and 115.33 kg ha^{-1} at 3.33 km h^{-1}. The results also show that 2.83 km h^{-1} is again the best forward speed due to least grain losses during operation. However, the cutting speed of 3.42 km h^{-1} showed the lower harvesting loss of 108.00±2.0 kg ha^{-1} as compared to that of the speed 4.53 km h^{-1} showing 109.43 kg ha^{-1} grain loss (Table 1 last column).

Overall fuel consumption is also important to evaluate the efficiency of mechanized harvesting in addition to grain loss control. Hence, overall fuel consumption was also valuated in the field. The forward speed of 3.33 km/ h^{-1} was found most economical in term of fuel consumption (i.e., 5.95±0.0026 L ha^{-1}) as compared to the forward speeds of 2.01 and 2.82 km h^{-1} (Table 2) which showed similar (i.e., 6.63±0.2664 L ha^{-1}) fuel consumption. Noby *et al.* (2018) and Ogunlowo and Olaoye (2017) have reported similar results after observing three cutterbar speeds (2.47, 3.1 and 3.5 km h^{-1}) of the reaper.

Table 1. Effect of forward and cutting speeds on grain harvesting loss (kg ha^{-1})

Cutting speed (km h^{-1})	**Forward speed (km h^{-1})**			**Means ± SEM**
	2.01	**2.82**	**3.33**	
3.42	109.33±1.0^{b*}	101.33±1.0^{c*}	113.33±0.3^{a*}	108.00±2.0^{a*}
4.53	110.67±0.3^{b*}	102.30±1.0^{c*}	115.33±0.3^{a*}	109.43±2.0^{a*}
Means ± SEM	110.00±1.0$^{b\times}$	101.82±1.0$^{c\times}$	114.33±0.5$^{a\times}$	

*Grain loss means with different alphabets are statistically different at LSD (0.05) = 2.53kg ha^{-1}, *Grain loss means with different alphabets are statistically different at LSD (0.05) = 1.46 kg ha^{-1}, ×Grain loss means with different alphabets are statistically different at LSD (0.05) = 1.79 kg ha^{-1}

Table 2. Effect of forward and cutting speeds on fuel consumption (L ha^{-1})

Cutting speed (km h^{-1})	Forward speed (km h^{-1}) 2.01	2.82	3.33	Means ± SEM
3.42	$7.68\pm0.026^{a*}$	$6.27\pm0.030^{b*}$	$5.94\pm0.0030^{c*}$	$6.63\pm0.2664^{a*}$
4.53	$7.77\pm0.023^{a*}$	$6.22\pm0.059^{b*}$	$5.95\pm0.0030^{c*}$	$6.65\pm0.2834^{a*}$
Means ± SEM	$7.72\pm0.026^{a*}$	$6.25\pm0.031^{b*}$	$5.95\pm0.0026^{c*}$	

*Fuel consumption means with different alphabets are statistically different at LSD (0.05) = 0.1027 L ha^{-1}, *Fuel consumption means with different alphabets are statistically different at LSD (0.05) = 0.0593 L ha^{-1}, *Fuel consumption means with different alphabets are statistically different at LSD (0.05) = 0.0727 L ha^{-1}

Control of grain harvesting loss is more important and cannot be compromised from economic point of view as compared to the fuel consumption (Figure 4).

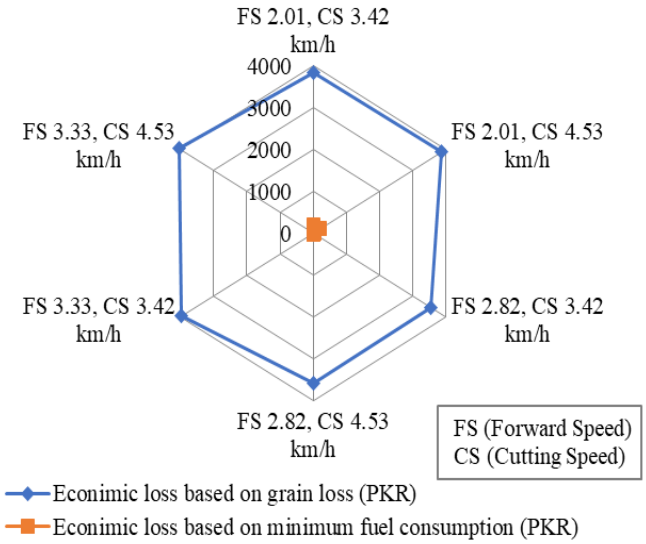

Figure 4. Economic comparison of grain loss and fuel loss at different forward and cutting speeds

There is a minimum grain loss of 3547 PKR at forward speed of 2.82 km h^{-1} and cutting speed of 3.42 km h^{-1} while the cost of extra fuel consumption with reference to the minimum fuel consumption is just 35 PKR as shown in Figure 4. This comparison is noticeable and helps to select the combination of forward and cutting speeds on the basis of minimum grain loss rather than the fuel loss. Therefore, a combination of forward speed (2.82 km h^{-1}) and cutting speed (3.42 km h^{-1}) was found most suitable for the minimum grain harvesting loss of 101.33±1.0 kg ha^{-1} at fuel consumption of 6.27±0.030 L ha^{-1}.

Table 3. Cutting index of power tiller operated reaper

Cutting speed (km h^{-1})	Operating speed (km h^{-1})	C.I = $\frac{C.S}{Os}$
2.59	2.01	1.28
3.42	2.82	1.21
4.53	3.33	1.36

Table 3 shows the cutting index of power tiller operated reaper. Cutting index is described with respect to the cutting and operating speeds. There are three cutting indices which were computed as 1.21, 1.28 and 1.36.

Field capacity and field efficiency: At 2.01 km h^{-1}, theoretical and effective field capacities were as low as 0.192 and 0.131 ha h^{-1}. Field capcities of 0.27 and 0.192 ha h^{-1} were found at 2.82. At 3.33 km h^{-1} speeds, theoretical and effective field capacities were recorded at 0.32 and 0.22 ha h^{-1} respectively (Fig. 5).

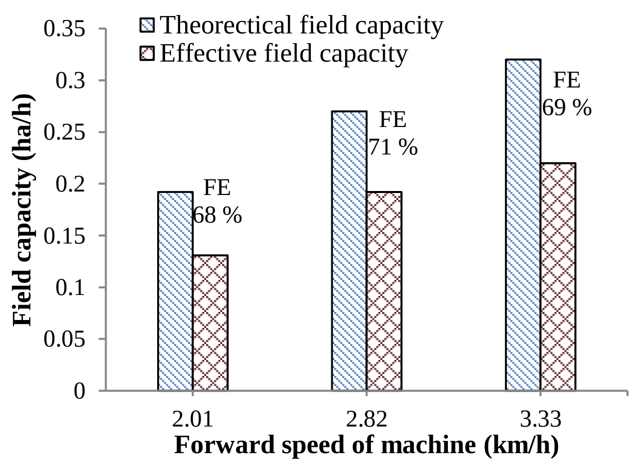

Figure 5. Relation of theoretical and effective field capacities with forward speed of machine

Table 4. Comparison of manual harvesting with harvesting by power tiller operated reaper

Observations	Power tiller operated reaper	Manual method of harvesting
Labor required (man-h ha^{-1})	7.02 [@1.14 ha/day (8h)]	160 [@20 man ha^{-1} in a day (8h)]
Operational cost (PKR ha^{-1})	1741 [Operator cost ha^{-1} (877 PKR ha^{-1})+Fuel cost ha^{-1} (5.94 L ha^{-1}×145.5 PKR/L)]	16000 [@800 PKR/man/day]
Grain loss (%)	2.7	3.45

***Locus of the cutter bar knife*:** The locus of the absolute velocity of any point on the knife was obtained graphically by a vector sum of the two motions that is relative and translatory motion as shown in Figure 6. Stroke length and speed of cutter bar knife is shown on x-axis. Most suitable forward speed (2.82 km h^{-1}) and cutting speed (3.42 km h^{-1}) were selected to plot the locus of cutter bar knife at any rotational angle of operating crank. The shape of the curved path (locus of cutter bar knife), described by the knife edges, indicates that at the beginning of the stroke of the knife edges, the speed of the machine prevails over that of the knife. Next the speed of the motion of the knife begins to exceed and, toward the end of the stroke, the speed of the motion of the machine exceed again (Figure 6). Most suitable forward and cutter bar speeds avoid any abnormal operation of crank and ultimately cutter bar prolonging the life of cutting mechanism.

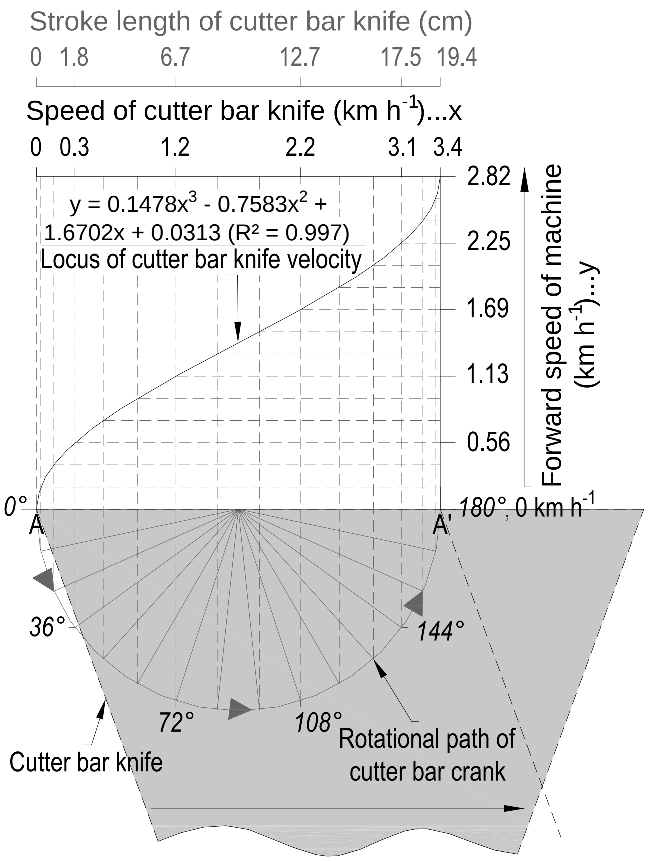

Figure 6. Locus of the cutter bar knife at different forward speeds of the machine

DISCUSION

The results imply that the combination of 2.82 km h^{-1} forward speed and 3.42 km h^{-1} cutting speed is the best for field operation due to its minimum grain harvesting losses (i.e., 101.33±1.0 kg ha^{-1} or ~2.5 % of the total yield). Similar results have also been reported in literature (Mirasi *et al.*, 2014; Iqbal *et al.*, 1980). A combination of forward speed (3.33 km h^{-1}) and cutting speed (3.42 km h^{-1}) showed least fuel consumption at 5.94±0.0030 L ha^{-1} (Table 2). These results are almost similar to Tripathi *et al.* (2018) who found the fuel consumption at 5-8 L ha^{-1} or equivalent 0.95-1.5 L h^{-1}. Almost all the self-propelled reapers have this range of fuel consumption.

For cutting speed of 3.42 km h^{-1}, a cutting index of 1.21 was found optimum for the minimum harvesting loss of 101.03 kg ha^{-1} (Table 3). Nalawade *et al.* (2009) and Pawar *et al.* (2008) also recorded the most suitable cutting index of 1.21 for their research studies.

The results proved that by increasing the forward speed of machine, theoretical and effective field capacities are increased as already mentioned by Davoodi and Houshyar (2010). The results were almost simlar to Jitendra (2018), Tripathi *et al.* (2018) and Alizadeh *et al.* (2007) who computed the similar field capacities ranging from 0.2 to 0.35 ha h^{-1}.

Higher field efficiency of 71% was recorded for the forward speed of 2.82 km h^{-1} which was the part of most suitable combination of forward and cutting speed (Figure 5). Comparatively lower field efficiency of 69% was found for the speed of 3.33 km h^{-1}. The above results are almost similar to Parida (2008) who found the 60 to 70% of field efficincies of reapers. Therefore, field efficiency of power tiller operated reaper used in this research was satisfactory.

The performance of power tiller operated reaper was compared with the manual harvesting operation frequently being used in Pakistan. For harvesting of wheat crop with power tiller operated reaper, only one man (operatore) with fair skills is required who can harvest 1.14 ha in one day. However, about 20 man ha^{-1} were required for manual harvesting. The requirement of labor, labor cost and grain loss percentage of power tiller operated reaper was compared with the manual harvesting method (Table 4). The total havesting cost of reaper was 963 PKR ha^{-1} while manual harvesting was almost 12000 PKR ha^{-1} (Table 4). These results were almost similar with the findings of (Gundoshmian *et al.*, 2010). It is estimated that the cost of manual harvesting is about 9 to 10 times higher than mechnical harvesting.

It is also well documented that the grain loss by manual practices are also higher (140 kg ha^{-1} or 3.5% of total yield) than mechanical harvesting. The results reported by Sattar *et al.* (2015) and Iqbal *et al.* (1980) described that manual harvesting losses may vary from 3 to 7%. The wheat harvesting season in Pakistan is also quite unpredictable as strong winds and rains are frequently reported in this season. It means that farmers with small land holding cannot afford to wait slow manual harvesting. In addition, the smaller field size do not allow to use heavy combine harvesters. Thus, adoptation of small power tiller reapers whith optimal performance parameters could not only help to harvest the wheat crop in time but also earn the better profits to uplift their livlihood.

Conclusions: This research was conducted to quantify the optimum cutting knife dynamics on the basis of cutting speed, operating speed, cutting index, field capacity and fuel consumption. In this study, the combination of machine's forward speed at 2.82 km h^{-1} and cutting speed at 3.42 km h^{-1} was found most suitable for minimum grain harvesting loss of 101.33±1.0 kg ha^{-1} which is only ~2.5 % of the total yield. On the other hand, least fuel (5.94±0.0030 L ha^{-1}) was consumed at the forward speed of 3.33 km h^{-1} while cutting speed of 3.42 km h^{-1} showed the least fuel consumption at 5.94±0.0030 L ha^{-1}. To achieve the minimum grain harvesting loss, fuel consumption can be compromised to a little extent. Therefore, a combination of forward speed at 2.82 km h^{-1} and cutting speed at 3.42 km h^{-1} with cutting index of 1.21 was found to be most acceptable for a minimum grain harvesting loss of 101.33±1.0 kg ha^{-1} at a fuel consumption of 6.27±0.030 L ha^{-1}. At this cutting index, higher field efficiency of 71% was also recorded for same combination of forward and cutting speeds. Locus of cutter bar knife for mentioned combination of forward and cutting speeds helped to examine the operation of crank and ultimately cutter bar, prolonging the life of cutting mechanism. The results and procedures discussed in this study are helpful in sustainable adaptation of small scale farm machinery, improving machine use efficiency and uplifting of small land holding farming community.

***Conflict of Interest*:** The authors declare that there is no conflict of interest.

***Authors' Contribution Statements*:** MY, SH and SB executed the field research, whereas MY, MAI, MI and MA conceived the idea and supervised the work.

REFERENCES

Alam, A. 2006. Future requirements of agricultural machines for mechanizing agriculture. Status of farm mechanization in India. Report, Indian Council of Agricultural Research, India. 175-196.

Alam, S., M. Rashedujjaman, M. Hossain and K. Hossain. 2017. Comparative Harvesting and Threshing Cost of Paddy by Combine Harvester and Self-propelled Reaper and Thresher. Journal of Environmental Science and Natural Resources.10:133-136.

Alizadeh, M.R., I. Bagheri and M.H. Payman. 2007. Evaluation of a rice reaper used for rapeseed harvesting. American-Eurasian Journal of Agricultural & Environmental Science. 2:388-397.

Bagheri, I., M. Alizadeh and M. Payman. Evaluation of a rice reaper used for rapeseed harvesting. Agricultural and biosystems engineering for a sustainable world. International Conference on Agricultural Engineering, Hersonissos, Crete, Greece, 23-25 June 2008. European Society of Agricultural Engineers (AgEng).

Bala, B., M. Haque, M.A. Hossain and S. Majumdar. 2010. Post harvest loss and technical efficiency of rice, wheat and maize production system: Assessment and measures for strengthening food security. *Final Report CF.*

Chaab, R.K., S.H. Karparvarfard, H. Rahmanian-Koushkaki, A. Mortezaei and M. Mohammadi. 2020. Predicting header wheat loss in a combine harvester, a new approach. Journal of the Saudi Society of Agricultural Sciences. 19: 179-184.

Davoodi, M.S. and E. Houshyar. 2010. Evaluation of wheat losses using New Holland combine harvester in Iran. American-Eurasian Journal of Agricultural and Environmental Science. 8:104-108.

Douthwaite, B., G.R. Quick and C.J.M. Tado. 1993. Stripping: A new approach to small-area rice harvesting. Philippine Journal of Crop Science. 18:119-127.

Gajakosvivek, A., K. Khambalkardhiraj, P. Bapu and K. Uddhao. 2013. Performance evaluation of self propelled vertical conveyor reaper for soybean crop. International Journal of Agricultural Engineering. 6:458-462.

Gundoshmian, T.M., H.R. Ghassemzadeh, S. Abdollahpour and H. Navid. 2010. Application of artificial neural network in prediction of the combine harvester performance. Journal of Food, Agriculture and Environment. 8:721-724.

Iqbal, M., G. Sheikh and J. Sial. 1980. Harvesting and threshing losses of wheat with mechanical and convential methods. Agricultural Mechanization in Asia (Japan). 11: 66-70.

Ismail, Z. and A. Abdel-Mageed. 2010. Workability and machinery performance for wheat harvesting. Misr Journal of Agricultural Engineering. 27:90-103.

Jitendra, S. 2018. Field evaluation of self propelled reaper cum binder through front line demonstration in wheat crop in Indore district of Madhya Pradesh. International Journal of Agricultural Engineering. 11:359-363.

Jun, H.-J., I.-S. Choi, T.-G. Kang, Y.-K. Kim, S.-H. Lee, S.-W. Kim, Y. Choi, D.-K. Choi and C.-K. Lee. 2016. Design and safety performance evaluation of the riding three-wheeled two-row soybean reaper. Journal of Biosystems Engineering. 41:288-293.

Khan, N.Z., M. Ahmad and A. Rasheed. 2003. Wheat production in Pakistan: Saga of policy disincentives. Pakistan Development Review. 42: 1-27.

Kumar, R., V. Paradkar and S. Singh. 2018. Economic analysis for self-propelled reaper binder over manual harvesting. International Journal of Communication Systems. 6:1219-1222.

Kurhekar, S. and S. Patil. 2011. Performance evaluation of self propelled walking type vertical conveyor reaper.

International Journal of Processing and Post Harvest Technology. 2:29-31.

Mandal, S., B. Bhattacharyya and S. Mukherjee. 2015. Design of rotary tiller’s blade using specific work method (SWM). Journal of Applied Mechanical Engineering. 4:1-6.

Mandal, S.K., B. Bhattacharyya and S. Mukherjee. 2013. Design optimization of rotary tiller blades: a critical review. Scientific Jour-nal of Pure and Applied Sciences. 2:260-269.

Mcmaster, G.S., R.M. Aiken and D.C. Nielsen. 2000. Optimizing wheat harvest cutting height for harvest efficiency and soil and water conservation. Agronomy Journal. 92: 1104-1108.

Mirasi, A., M.A. Asoodar, M. Samadi and E. Kamran. 2014. The Evaluation of wheat losses harvesting in two conventional combine (John Deere 1165, 955) in Iran.

Nalawade, S., P. Turbatmath and A. Gajakos. 2009. Design and development of tractor operated Jowar reaper windrower. New Agriculturist. 20:75-81.

Noby, M.M., M.K. Hasan, M.R. Ali, C.K. Saha, M.M. Alam and M.M. Hossain. 2018. Performance evaluation of modified BAU self-propelled reaper for paddy. Journal of the Bangladesh Agricultural University. 16:171-177.

Ogunlowo, Q. and J. Olaoye. 2017. Development and performance evaluation of a guided horizontal conveyor rice harvester. Agrosearch. 17:66-88.

Omran, M.S. 2008. A comparative study of the most widely harvesting systems for wheat crop in Egypt. Misr Journal of Agricultural Engineering. 25:804-823.

Parida, B. 2008. Evaluation, constraints and acceptability of different types of vertical conveyer reaper for harvesting rice in coastal Orissa, India. Ama, Agricultural Mechanization in Asia, Africa & Latin America.pp. 39:1-29.

Pawar, C., N. Shirsat and S. Pathak. 2008. Performance evaluation of combine harvester and combination of self propelled vertical conveyor reaper with thresher for wheat harvesting. Agriculture Update. 3:123-126.

Prabhakar, D. and P. Janardan. 2000. Modification and evaluation of a self-propelled reaper for harvesting soybean. AMA, Agricultural Mechanization in Asia, Africa and Latin America. 31:43-46.

Prakash, R.J., B.a.I. Kumar, G.A. Reddy and K.R. Reddy. 2015. Performance evaluation of reaper-binder in rice crop. International Journal of Agricultural Engineering. 8:232-238.

Rahman, M., M. Hossain and A. Islam. 2004. Modification and performance evaluation of self propelled reaper. Journal of IEB/AE. 31:23-28.

Ramulu, C. and R.P.A. Deepshika. 2018. Machinery for residue management of different crops: A review. Journal of Pharmacognosy and Phytochemistry. 7:2203-2207.

Sattar, M., M.U. Din, M. Ali, L. Ali, M.Q. Waqar, M.A. Ali and L. Khalid. 2015. Grain Losses of Wheat as Affected by Different Harvesting and Threshing Techniques. International Journal of Research. 2:20-26.

Shamshiri, R., R. Ehsani, J. Maja and F. Roka. 2013. Determining machine efficiency parameters for a citrus canopy shaker using yield monitor data. Applied engineering in Agriculture. 29:33-41.

Shamshiri, R. and W.I.W. Ismail. 2013. Exploring gps data for operational analysis of farm machinery. Research Journal of Applied Sciences, Engineering and Technology. 5: 3281-3286.

Shreen, F., S. Badr and M. Morad. 2016. Maximizing wheat crop yield using a mobile thresher at small holdings. Agricultural Engineering International: CIGR Journal. 18: 63-73.

Singh, J. 2005. Scope, progress and constraints of farm mechanization in India. Status of Farm Mechanization in India. New Delhi: Indian Agricultural Statistics Research Institute 48-56.

Tabatabaekoloor, R. Development a tractor front-mounted rice reaper with a hydro-motor driven mechanism. International Conference on Agricultural Engineering-AgEng 2010: towards environmental technologies, Clermont-Ferrand, France, 6-8 September 2010. Cemagref.

Tiwari, P. and L. Gite. 2002. Physiological responses during operation of a rotary power tiller. Biosystems Engineering. 82:161-168.

Tripathi, A., B. Mishra, M. Kumar and N.K. Patre. 2018. Field Performance of Machine for Harvesting of Wheat and Linseed. International Journal of Pure & Applied Bioscience. 6:1512-1519.

Tsegaye, A., A. Qabaradin, A. Tilaye and D. Fufa. 2017. Evaluation of Walking Behind Harvester for Wheat Crop. Regional Review Workshop on Completed Research Activities.pp.1- 44.

Yamin, M., W.I.B.W. Ismail, S.A. Aziz, M.S.B.M. Kassim, F.N. Akbar and M. Ibrahim. 2022. Design considerations of variable rate liquid fertilizer applicator for mature oil palm trees. Precision Agriculture.pp.1-36.

Yamin, M., A.R. Tahir, A. Nasir and M. Yaseen. 2011. Short communication: Studying the impact of farm mechanization on wheat production in Punjab-Pakistan. Soil and Environment. 30:151-154.