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Assessment and Determination of Seed Corn Combine Harvesting Losses and Energy Consumption

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ABSTRACT

Field evaluation to measuring combine losses was conducted typically on seed corn field because of high economic importance of seed corn in Iran. Because seed corn is alive, harvesting operation should be done precisely with fewer losses. For this purpose data were collected and analyzed for different cylinder and ground speeds. Pre-harvest, gathering, and processing losses were measured. The results showed the total harvesting loss was 9.30% which combine loss was almost 8.56% with feeding rate of 2.48 kg ears per second. The highest losses occur in processing (threshing) (5.39%) because of elimination all cracked seeds (any crack in seeds decrease the seed generation power). The effect of travel speed was significant for gathering and threshing (quality) losses while cylinder speed had a significant effect on threshing (quality and quantity) losses. The lowest total combine loss (7.60%) was measured at 3 km h^{-1} ground speed with 400 rpm cylinder speed and the highest value (7.19%) belonged to 5 km h^{-1} ground speed with 600 rpm cylinder speed. Energy consumption during harvesting seed corn was calculated 1.8 GJ ha^{-1} which the diesel fuel input was the highest energy consumer with almost 1.2 GJ ha^{-1} that was 70% of total energy use.

1. Introduction

Waste management has become increasingly important as population growth, urbanization and mass consumption are drivers for a mounts and toxicity of waste (Eriksson and Bisaillon, 2011). The high growth of world population and need to supply food, led to production of high yield crops such as corn. Corn has been for many years an important cereal crop in the world. Corn production in recent years has increased more than wheat and rice and has taken the first rank in all world crops. United States of America is the leading country in corn production followed by China, Brazil, Mexico and Argentina (Anonymous, 2008a). In 2008, 2% (225,639 ha) of the whole area under cultivation in Iran was allocated to corn with an annual production of almost 1.6 Mt (Anonymous, 2008b). Statistics show that number of farmers in corn production is increasing; in 2006 the area occupied by corn comprised to 307,015 ha while in 2008 the number increased to 225,639 ha (Anonymous, 2008b). The corn planting area is increasing but there are many agro-technical issues yet to be solved, among them the problem of seed corn harvesting. Beside corn, seed corn which is utilized for cultivation should be out of any crack, break or damage (high germination power) to produce a healthy and strong plant and accordingly perfect seeds are derived. To achieve this, it should be attempted to perform agricultural harvesting operations precisely. Iranian agricultural statistic data revealed the annual production of 15,500 t in 2009 for seed corn with the average yield of 2.28 t ha^{-1}. Ardabil is the most important province in seed corn production of Iran, followed by Fars and Korasan-Razavi provinces (Anonymous, 2008b). The main goals of mechanized harvesting are: on time harvesting and threshing with least loss. Combines are made to harvest different types of grain crops under variable, often adverse, conditions. Therefore, combines may function well below their optimum conditions (Srivastava et al., 1990). Every kilogram of seed corn (or any other crop) that is saved by careful use of combine, adds to profit a hectare (Hanna and Fossen, 1990). Prevention of losses is generally considered to be good for the environment and society at large, but there is little quantitative evidence assessing the environmental aspects of waste prevention (Gentil et al., 2011). Proper management tools are essential to minimize potential risks and ensure maximum profits for producers (Nybo, 2005). To keep harvesting losses low, it is needed to know where losses occur, how to measure them, what reasonable loss levels are, and what machine adjustment and performing practices will reduce losses. Significant seed losses occur because of natural shedding and mechanical harvesting (Price et al., 1996). Corn harvesting can begin when grain moisture drops below 30%. However, most producers allow corn to dry in the field until grain moisture is between 18 to 25%. Harvesting corn when grain moisture levels are high can result in excessive drying costs, kernel damage, and harvest loss from improper threshing. Allowing corn to stay in the field too long can result in excess harvest loss from stalk lodging, ear drop, or kernel shattering (Humburg et al., 2009). There are two categories of losses: pre-harvest and total harvesting losses (Hanna and Fossen, 1990; Shay et al., 1993). Pre-harvest losses are ears that drop from the stalk before harvesting begins. These losses are not caused by the combine and are caused by high winds, hail, or similar weather event, from disease or insect pressure, or from a combination of these cases (Huitink, 2008; McNeill and Montross, 2002). The University of Arkansas researchers recommended harvesting corn between 15-18% moisture

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content to avoid more loss (Anonymous, 2008c). While Nicolai and Hutchinson (2006) suggested harvesting at higher moisture content in certain subjects may be useful to reduce loss, although higher drying costs are still a disadvantage.

Total Harvesting losses can be separated into three types of losses categories. Gathering losses occur at the front of the combine, and consist of ears (missed or dropped by corn head) and kernels (shelled by the stalk rolls on the corn head). Threshing and separating losses are found on the ground behind the combine. Threshing losses are damaged kernels in the tank and kernels attached to pieces of cob that were not shelled by the combine rotor or cylinder. Separating losses are loose kernels that were not shaken out of the cobs and husks and were lost over the back of the combine (Humburg et al., 2009; Sumner and Williams, 2009).

There are some causes in combine harvester that can reduce corn losses as follows: ground speed, header height, concave, cylinder or rotor speed and cleaning unit (Digman, 2009), So, achieving proper combine setting (ground speed, cylinder speed, cleaning airflow, snapping rolls and spacing between plates) (Hanna, 2008) can help increase combine efficiency, increase grain quality and minimize field losses. Although harvesting losses cannot be removed, they can be reduced to 63 kg ha^{-1} in corn (Hanna and Fossen, 1990).

Bainer et al. (1955) tested combines equipped with six different gathering attachments. The entire group of attachments was experimental and of two general types: those performed as headers, cutting enough stalks to insure getting the ear and then introducing this portion of the plant into the cylinder and those that removed the ears from the stalk by stripper bars mounted immediately above snapping rolls. The total harvesting loss was about the same for machines equipped with either gathering attachment. Shelled corn loss for the snapper-type gathering unit was more than three times that lost by the header.

Ayres et al. (1972) measured visible in-field losses of 84 combines in North Central Iowa. They found that a corn head row spacing difference of 5 cm from the harvested rows resulted in another 82 kg ha^{-1} visible machine loss and that 65% of machine loss was at the corn head.

Gliem et al. (1990) found Ohio farmers to have total visible field losses in corn of approximately 1% of estimated yield under good harvesting conditions. The average ground speed of 52 combines measured in corn fields was 4.5 km h^{-1}.

Hanna et al. (2002) made a study on corn combine harvester and compared visible machine losses of a 76 cm corn head used on 76 cm and 38 cm rows and a single gathering chain of 38 cm corn head used on 38 cm rows. The results illustrated on matched row spacing, machine losses were generally similar between the 76 and 38 cm corn head and total machine loss of the conventional corn head (76 cm) was significantly less than that of the single gathering chain corn head. Harvesting at a moisture level (19-24%) will provide a good balance between minimizing harvest losses and keeping grain drying costs down. Harvesting at lower moistures can increase mechanical losses due to ears drop, stalk lodging and kernel shattering.

Vagts (2002) reported losses as high as 1260 kg of corn per hectare behind a poorly adjusted combine operating in weedy or severely lodged corn. Vagts indicated that harvesting losses cannot be completely eliminated, but they can be reduced to 63 to 126 kg ha^{-1} if operator spends enough time to check the performance of combine.

A research was done in North Dakota University that showed the place that losses occur and how to measure them and found the relationship between field losses and delayed harvesting (delaying increase machine and total losses to 7.2 and 13.4%, respectively) (Anonymous, 1997).

Morvaridi et al. (2008) analyzed the effect of ground speed and cylinder speed of corn combine harvester. Results indicated that the effect of ground speed on header loss and thresher loss was not significant while the effect of cylinder speed were significant on thresher loss. The highest total loss (5%) was calculated at ground speed of 2.23 km h^{-1} with cylinder speed of 550 rpm.

Waelti et al. (1969) studied the amount of corn harvesting losses in various varieties and harvesting dates. The results were showed, for most varieties, the losses increased rapidly as the grain moisture dropped below 25%. Ear drop losses were summed up to 85 to 95 % of all losses before or during the harvesting operation. Large differences in these losses existed among different varieties. The results indicated that poor ear attachment (weak ear shank) was a major factor causing very high ear losses for some varieties at kernel moisture below 25%.

Zhang et al. (2009) evaluated the effects of different planting row space on corn yield and machinery harvesting losses. Analysis revealed that the different row space (50, 60 and 70 cm) affects the quality of machinery harvesting significantly (12.23, 7.49 and 7.88% loss, respectively), while it had little effect on theoretical yield (9, 9.24 and 9.29 t, respectively).

Quick (2003) established a hyperbolic relationship between grain damage and harvested yield for corn combines. He found a certain "sweet spot" where the harvested or bin yield is optimal under the given crop conditions.

Corn picker field tests showed that ground speed and snapping roll adjustment are the most important factors determining picking losses (King et al., 1955).

Energy, being the capacity to do work, is at the heart of all human activities, especially, those concerning the production of goods and services (Canakci and Akinci, 2006; Fadavi et al., 2011).

Harvesting and threshing of grain crops are two major farm operations requiring considerable energy (Baruah and Panesar, 2005). Besides being major energy consuming operations, these operations are also considered critical, if delayed huge grain loss is resulted (Bector and Singh, 1999). Harvesting with combine machines maintains the timeliness and hence, prevents loss. However, the supply of sufficient amount of energy must be measured for timely operation of harvesting. Some studies have been carried out to find energy and power requirements of harvesting and threshing machines (Baruah and Panesar, 2005; Burrough, 1954; Spokas and Lideikis, 1996).

Based on other researches results, it is concluded that travel and cylinder speed are the most important factors in combine harvesting that can change the amount of losses. So, the main goal of the present study is to consider the effect of cylinder speed and ground speed of seed corn combine harvester on seed corn harvesting losses. Also, the energy consumption of seed corn combine harvesting was evaluated as the secondary objective.

2. Materials and methods

The experiment was conducted in farms of Seed and Plant Improvement Research Institute (SPIRI) located in Iran in 2011. The effect of two factors (cylinder and ground speed) on seed corn combine losses was evaluated. The treatments included 400, 500 and 600 rpm for cylinder (or rotor) speed and 3, 4 and 5 km h^{-1} for ground speed. The test was done in split plot design based on complete randomized block with three replications.

Each plot consists of 30 m long and 3 m width. The cultivated seed corn variety was single cross 704, with row distance of 76 cm and the seed corn harvesting machine used was a four-row CLAAS MEDION.

To measure field losses, a representative field with about 2500 m^2 was chosen. Corn normally dries at the rate of 0.5 to 1% moisture content per day in the field. Approximately two weeks before harvest is a good time to begin measuring corn moisture content (Huitink, 2008). To measure grain moisture content, 5 seed corn ears were selected randomly and several rows of corn kernels from the full length of the ear were removed. The seeds were mixed thoroughly. RASA 3000 moisture meter was used to determine the moisture content and three moisture readings were taken and the results were averaged. Tacho Hi tester (HIOKI 13404) rpm meter was applied to measure the cylinder (or rotor) speed with five replications. In order to find the combine ground speed, a typical chronometer (stop watch) was used to determine the time passed in a 30 m combine run. The values of five replications of measured ground speed were averaged.

Researchers have reported some techniques to measure corn combine losses (Hanna and Fossen, 1990; Huitink, 2008; Sumner and Williams, 2009). As it was mentioned before, seed corn harvesting losses are classified into three categories:

1. Pre-harvest losses are ears that drop from the stalk before harvesting begins. To measure this kind of losses, before harvesting all drop ears in experimental plots were collected, shelled and weighed.
2. Gathering losses are consisted of seed corn ears and kernels that are missed by combine header in front of combine. To calculate this loss, a wooden quadrangular frame (Figure 1) with area of 0.25 m^2 was used. Materials in four replications for every plot (30×3.75 m) were collected, weighed and combined; therefore, the sample size represented losses for 1 m^2. Frames should cover the combine row width.

Figure 1- Quadrangular frame used in the experiment (0.25 m^2)

3. Processing losses are categorized into two groups, threshing and separating losses. These losses are found on the ground behind the combine and combine tank. Threshing losses are kernels attached to pieces of cob not being shelled by the combine cylinder (quantity loss) and damaged kernels in tank (quality loss). Separating losses are kernels that were not shaken out of the cobs and husks and were lost over the back of the combine. A wooden rectangle frame (0.5×0.8 m^2) (Figure 2) was used over the back of combine. Five samples (representing a total area of 2 m^2) were taken for attached (threshing loss) and separated kernels (separating loss) and were weighed in every experiment unit. The frame width was 0.5 m and was almost fixed to the combine backside. In every experimental unit, three kernel samples were taken from combine tank to find the amount of broken and damaged kernels. The samples (seeds) were studied with a magnifier carefully to find any damage in them. Finally, the average weight for damage and broken seeds was calculated.

Figure 2 - Rectangular wooden frame (0.4 m^2)

To find the effect of combine cylinder and ground speed on harvesting losses, a split plot design was used. Cylinder speed (400, 500, 600 rpm) and ground speed (3, 4, 5 km h^{-1}) were as the main plot (MP) and subordinate plot (SP), respectively.

To know the feed rate Eq.(1) was applied for each ground speed:

$$FR = FC \times Y \tag{1}$$

Where 'FR' is feed rate (kg h^{-1}), 'FC' field capacity (ha h^{-1}) and 'Y' the total yield (kilogram ears per hectare).

To calculate the field capacity Eq.(2) was utilized:

$$FC = \frac{S \times W}{10} \tag{2}$$

Where; 'S' is the ground speed (km h^{-1}) and 'W' is the combine corn head width (m).

The machinery, diesel fuel and labor (operator) as inputs are mentioned to calculate amount of energy use in seed corn harvesting. By using energy coefficient equivalents (Table 1) energy consumption of all inputs were calculated. Energy used of machinery (seed corn combine harvester) was estimated by Eq.(3):

$$ME = E \times G \tag{3}$$

Where; 'ME' is the machinery energy (MJ), 'E' the production energy of machine (MJ kg^{-1}) and 'G' machine weight (kg).

Table 1- Energy equivalents of inputs in seed corn harvesting

Inputs (unit)	Energy equivalent (MJ $unit^{-1}$)	Reference
1. Combine (kg)	116	(Kitani et al., 1999)
2.Labor (Male) (h)	1.96	(Bojaca and Schrevens, 2010; Kitani et al., 1999; Singh and Mittal, 1992)
3.Diesel fuel (L)	56.31	(Demircan et al., 2006; Mohammadi and Omid., 2010)

All collected data were entered into Excel 2010 spreadsheets and the amount of losses (kg ha^{-1}) and energy values of seed corn combine harvester were calculated. To find the effect of combine cylinder and ground speed on harvesting losses, ANOVA test was applied using SPSS18 software in split plot design. Also, Duncan compare mean test was applied to compare means.

3. Results and discussion

Seed corn yield was found to be 4,825 kg ha^{-1}. The moisture content was calculated as 19% by using RASA 3000 moisture meter and it was found to be near (Huitink, 2008) seed moisture recommendation for harvest .The amount of feed rate for 3, 4 and 5 km h^{-1} were calculated as 1.49, 1.98 and 2.48 kg ears per second, respectively.

3.1. Total losses in seed corn combine harvesting system

All types of losses (pre-harvest, gathering, processing (threshing and separating)) were calculated and are listed in Table 2. Total loss in seed corn combine harvester was found to be 449 kg ha^{-1} (9.30%). As it can be seen, the highest loss occurred in threshing unit with the share of 5.39% followed by gathering, pre-harvest and separating losses with share of 2.92, 0.74 and 0.25%, respectively. The amount of total seed corn harvest loss was higher than that of (Sumner and Williams, 2009) which was reported as 2-4 percent. The high harvesting losses that is reporting in this study is referred to eliminate all cracked seed (any crack in seeds decrease the seed generation power). The most difference between this study and other studies is the kind of harvesting crop. Seed corn as it was specified in previous should be out of any cracked and damaged seed and for this reason the threshing losses is higher than other researches.

Table 2– The amount of losses in seed corn combine harvester

Kind of loss	Value (kg ha^{-1})	Percentage (%)
1. Pre-harvest loss	35	0.74
2. Gathering loss	141	2.92
3. Processing loss	272	5.64
Threshing loss	260	5.39
Separating loss	12	0.25
Total loss	449	9.30

3.2. The effect of ground and cylinder speed on gathering loss of seed corn combine harvester

Statistical analysis showed that ground speed significantly affected the amount of gathering losses while the effect of combine cylinder speed and the interaction effect of cylinder and ground speed were not significant (Table 3).

Table 3– Analysis of variance for gathering losses

S.O.V	df	Sum of Squares		Mean Square	F
Replication	2	353.407		176.704	0.58^{ns}
Cylinder Speed	2	147.852		73.926	0.24^{ns}
Error (cylinder speed)	4	1214.148		303.537	
Marginal Plot	8	1715.407			
Ground Speed	2	2438.296		1219.148	6.03*
Cylinder Speed × Ground Speed	4	1990.593		497.648	2.46^{ns}
Error (ground speed)	12	2427.111		202.259	
Subordinate Plot	18	6856.000			
Total	26	8571.407			

^{ns} not significant * significant at 5% level ** significant at 1% level

The mean value of gathering losses for 5 km h^{-1} ground speed was significantly (p<0.01) higher than that of 3 km h^{-1} (3.15 and 2.67%, respectively) (Figure 3). Excessive ground speed causes stalks to be crump and leads the ears to fall off the stalks ahead of the gatherer chains (Griffin, 1987) and out of the gathering unit. The results were in agreement with the results of (EbrahimiNik et al., 2008; Fouad et al., 1990; Hanna et al., 1998; Morvaridi et al., 2008; SheikhDavoodi and Houshyar, 2010) that indicated higher ground speed leads to more gathering losses.

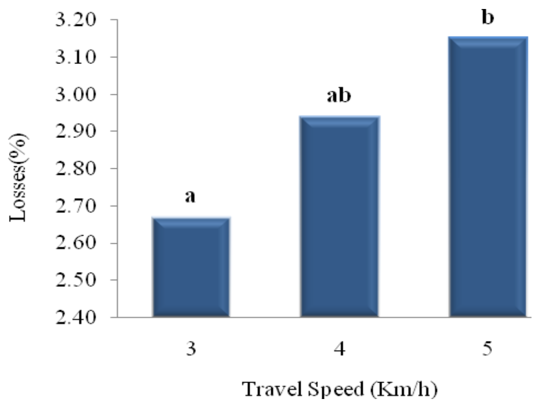


Figure 3- Gathering losses in different travel speeds

3.3. The effect of ground and cylinder speed on threshing loss of seed corn combine harvester

Because seed corn harvesting is sensitive to existence of any crack and damage and to have a better evaluation of the two specified factors effects on threshing losses, the losses were divided into two categories (quality and quantity). The threshing quality losses consist of any damaged, cracked and broken kernels which can be found in combine tank, while the threshing quantity losses include kernels attached to pieces of cobs that were not shelled by the combine cylinder.

The effects of combine cylinder and ground speed on quality losses were significant at 1% and 5% level, respectively while the interaction effect was not significant. The results reflected the fact that increasing cylinder speed results in significant threshing quality losses (cracked and broken kernels), where the losses were 4.70, 5.18 and 5.28% for 400, 500 and 600 rpm, respectively (Figure 4). As (Morvaridi et al., 2008) said, the most important factor that produces cracked and broken seed corn is cylinder speed and to reduce these losses lower cylinder speed is recommended (Metianu et al., 1990). More cylinder speed means more pressure and strokes to seeds that appears in form of cracked and broken in seed corn.

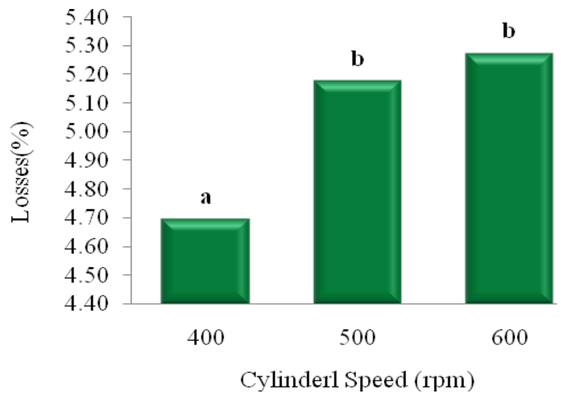
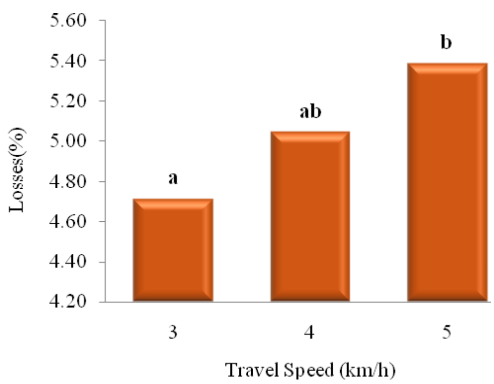


Figure 4- Threshing losses (cracked and broken kernel) in different cylinder speeds

Duncan compare mean test for ground speed revealed that there is no difference between losses in 4 and 5 km h^{-1} ground speed; however, the threshing quality losses in 3 km h^{-1} was significantly lower than that of 5 km h^{-1} (Figure 5). The results was not similar to Morvaridi et al., (2008) study. They believed, by increasing the ground speed, the amounts of entered materials increase so the cylinder strokes are absorbed by them and in this regard the amount of damaged seeds decreases. In the study carried out by SheikhDavoodi and Houshyar (2010) on wheat combines results showed that an increase in travel speed leads to increase in threshing losses.



The results of ANOVA test for the effect of cylinder and ground speed on threshing losses (quantity) is shown in Table 4 and it is clear that the effect of cylinder speed and interaction effect on seed corn harvester threshing losses (quantity) were significant at 1% and 5%, respectively.

As it is shown in Figure 6, the interaction effect of higher cylinder and ground speed leads to decrease in the amount of threshing quantity losses. It is worthy to mention that the result of an increase in cylinder speed is a decrease in threshing losses (quantity) but by increasing ground and cylinder speed at the same time the amount of entrance ears are increased and by more pressure and stroke from cylinder and ears (that works like a thresher), better removing kernels from cobs is observed by the threshing unit. It is extremely essential to calculate the best ground and cylinder speed to minimize the amount of threshing quality and quantity losses together. The results were similar to that of Morvaridi et al. (2008) and SheikhDavoodi and Houshyar (2010) research results.

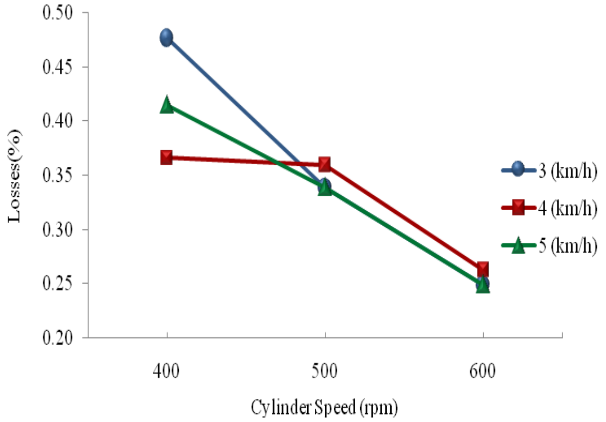


Figure 6 - The interaction effect of cylinder and ground speed on threshing losses (quantity)

3.4. The effect of ground and cylinder speed on separating (cleaning) loss of seed corn combine harvester

The results of ANOVA test represented the no significant effect ($p<0.05$) of ground speed and travel speed on seed corn combine harvester separating losses. Due to less seed corn yield in comparison with grain corn, the separating unit of combine can separate the seeds and cobs easily and increasing the ground speed to the highest value (5 km h^{-1}) had no significant effect on function of this SheikhDavoodi and Houshyar (2010) found that the increase in cylinder and blower speed and the decrease in ground speed in wheat combine harvesters result in the least amount of cleaning losses.

3.5. The effect of ground and cylinder speed on Total loss of seed corn combine harvester

Figure 7 shows the amount of total machine loss in different cylinder and ground speeds. As can be seen total machine loss is lower (in 3 km h^{-1}) than that in 4 and 5 km h^{-1} ground speeds. The feeding rate in 3 km h^{-1} ground speed has the lowest level, showing that the gathering, threshing and separating units work properly with the least amount of losses. On the other hand, at the highest ground speed (5 km h^{-1}) with maximum feeding rate, some ears drop out of gathering unit and the corn head fails to gather all the eras, some kernels cannot be removed from cobs and finally the amount of damaged and cracked seeds increases with more pressure from other ears (extra feed rate) in threshing unit. Furthermore, at higher ground speeds some kernels cannot be separated and fall behind the combine due to more corn cobs in the separating unit. With the results of Figure 7 it was indicated that applying the least cylinder and ground speed (400 rpm and 3 km h^{-1}, respectively) leads to decrease the total seed corn harvesting losses.

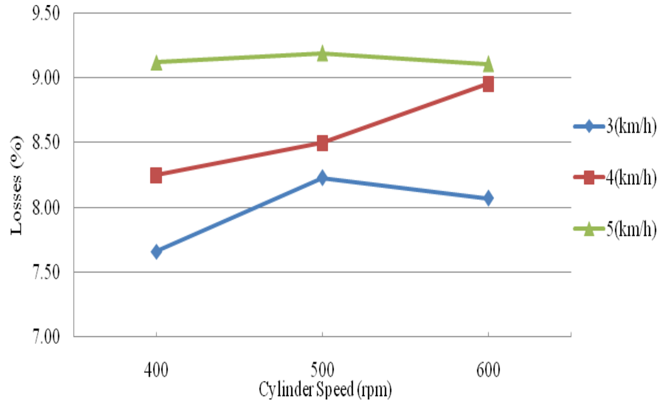


Figure 7- The amount of total combine losses in different cylinder and ground speed

3.6. The energy consumption in seed corn combine harvester

To calculate the amount of energy consumption in seed corn combine harvester the quantity of each input was determined and by multiplying with corresponding energy equivalent the value of energy consumption was calculated. As it is shown in Table 5 total energy consumption in seed corn combine harvesting was almost 1.8 GJ ha^{-1} where diesel fuel with share of 70% was the highest energy consumer followed by machinery and labor (machine operator) inputs energy (29.64 and 0.35%, respectively). The most reasons for high energy consumption in diesel fuel inputs is low field efficiency of seed corn harvesting. To prevent the creation of hard layer, trucks were not allowed to enter in seed corn farms so combines are forced to go out of the farm to empty the full tank which leads to decrease the field efficiency and high diesel fuel energy consumption.

4. Conclusion

This study analyzed the effects of cylinder and ground speed on seed corn losses and the harvesting energy consumption in combine harvester. Based on the results, conclusions are drawn as follows:

1. All kinds of losses measured and the average value of pre-harvest, gathering, threshing and separating loss were 0.74, 2.92, 5.39 and 0.25%, respectively. The high threshing loss was referring to seed corn high sensitivity against cylinder speed. Using lower cylinder and ground speed is recommended to decrease these losses. Total harvesting loss was measured as 449 kg ha^{-1} that was equal to 9.30% of the crop yield.
2. The effect of ground speed on gathering losses was significant ($p<0.01$) while the other factors did not. The highest loss belonged to 6 km h^{-1} (2.48 kg ears per second feed rate) with average loss of 3.15% of total seed corn yield. In Lower ground speeds, there is enough time for corn head to gather all ears with the lowest amount of losses and it is easy for operator to control the corn head in corn rows in a specific height.
3. According to results of this study, ground and cylinder speed had significant effect on threshing quality losses. Because of high sensitivity in seed corns, it is essential to apply lower ground and cylinder speed to reduce these losses (cracked and damaged seeds). At recommended speeds, threshing unit works properly and has enough time to thresh all ears with the lowest stroke at kernels.
4. The significant effect of cylinder speed on threshing quantity losses showed that increasing cylinder speed lead to removal of all kernels from corn cobs and the attached kernels in cobs behind combine would decrease.

Table 4– Analysis of variance for threshing losses (quantity)

S.O.V	df	Sum of Squares	Mean Square	F
Replication	2	5.852	2.926	0.71 ^{ns}
Cylinder Speed	2	289.185	144.593	34.86**
Error (cylinder speed)	4	16.593	4.148	
Marginal Plot	8	311.630		
Ground Speed	2	7.630	3.815	1.84 ^{ns}
Cylinder Speed × Ground Speed	4	38.148	9.537	4.60*
Error (ground speed)	12	24.89	2.074	
Subordinate Plot	18	70.67		
Total	26	382.296		

^{ns} not significant * significant at 5% level ** significant at 1% level

Table 5- Amounts of energy inputs in seed corn combine harvester

Inputs(unit)	Quantity by area (unit ha^{-1})	Energy equivalent (MJ unit^{-1})	Total energy (MJha^{-1})	Percentage (%)
1. Machinery(h)	1.33	409.87	546.49	29.64
2.Diesel Fuel(L)	27	47.8	1290.6	70
3. Labor(h)	3.33	1.96	6.53	0.35
Total energy input			1843.62	100

5. The results of separating unit losses indicated that ground speed cylinder speed had no significant effect on losses. Results revealed the lowest separating losses in lesser ground speed. At this speed (minimum feed rate (1.49 kg s^{-1})), the amount of cobs and other materials in separating unit is minimized so this unit can work properly to reduce the separating losses.

6. The effect of two specified factors on total losses showed that by increasing feed rate (from 1.49 to 2.48 kg s^{-1}) the amount of machinery losses increases and in high cylinder speed (600 rpm) total loss is higher. The results of this study indicated the minimum losses occur at 3 km h^{-1} ground speed with 400 rpm cylinder speeds.

7. Energy analysis indicated 1.8 GJ ha^{-1} energy consumption in seed corn combine harvesting system. With lack of good (efficient) management, diesel fuel consumption was high (1,290 MJ ha^{-1}) that was 70% of total energy consumption in harvesting system. Allowing trucks with wider tires (to prevent soil compaction) to enter the field and to stop extra combine moving is recommended.

At the end, based on this study, it is recommended that proper cylinder and ground speed should be adjusted in order to minimize the losses. Harvesting in correct moisture content leads to decrease the pre-harvest losses and using proper field management can decrease amount of diesel fuel consumption.

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