INFLUENCE OF CUTTING HEIGHT AND FORWARD SPEED ON HEADER LOSSES IN RICE HARVESTING

R.Bawatharani,
M.H.M.A.Bandara,
D.I.E Senevirathne

ABSTRACT

A field experiment was conducted at Farm Mechanization Research Centre (FMRC), Anuradhapura, Sri Lanka to investigate the header grain losses and quality of the paddy grains with respect to three levels of cutter bar heights 10, 15, 20 and 25 cm and forward speeds of 2.4, 3.84 and 4.28 km h^{-1}. A randomized complete block design under split plot arrangement with three replications were used to study the effect of cutting height and forward speed on header losses. The forward speed was considered as the main plot factor whereas cutting heights were considered as subplot factors. The dimension of each experimental plot was 10m x 4m. The header losses were evaluated using CLAAS C210 combine harvester equipped with a reel-type header. The results revealed that the cutting heights of 10 cm, 20 cm and 25 cm resulted in greater header losses. The cutting height of 25 cm resulted in significantly greater header loss of 37.04 kg/ha accompanied by a significantly lowest header losses of 23.66 kg/ha at the cutting heights of 15 cm. The forward speed of 4.28 km/h had significantly highest loss of 42.41 kg/ha, whereas significantly lowest loss of 23.96 kg/ha was associated with the forward speed of 2.4 km/h and at 3.84 km/h which were not significantly different from each other. The cutting height did not have any significant impact on grain damage. However, the forward speed of the harvester had significant effect on decreasing the grain damage. A strong negative relationship between forward speed and the grain damage was observed (R^2= 0.99) at 20 cm and 25 cm cutting heights.

Keywords: combine harvester, cutter bar, forward speed, header loss, reel

Introduction

As known, rice crop is too sensitive to harvesting operation due to the high percentage of grain losses affecting on total yield. Hence, efficient harvesting is a main concern for the farmers to reduce grain losses and at such stage, cutting height of harvesting operation is a main criterion. Combine Harvesting is a successful answer to shortage of manual labour for harvesting paddy crop since fast and efficient method of paddy harvesting is the immediate need of farmers in Sri Lanka. It is defined as that all harvest work from reaping, threshing, grain separating and cleaning are all completed by one combine harvester. Comparing with the separate harvest, this method has higher working efficiency and lower labour consumption and also save time. However, the machine is quite complicated and expensive. The combine requires a field with large enough area and flatness with qualified technicians to manage and service. There are many factors contributing to the performance of combine harvesters and they can be divided into machine and plant factors. Machine variables include combine forward speed, peripheral speeds of combine devices, and feeding rate. Moreover, the plant variables such as variety, moisture content and degree of maturity are considered as critical factors. The above mentioned factors affect directly on the grain losses, energy requirements, and efficiency, which in return, influence crop yield, and total operational cost. Therefore, care should be taken to operate the combines to minimize both losses because combine harvesters encounter problems with grain losses and frequent breakdowns (Bawatharani *et al.,* 2013).

The height at which the rice crop is cut at harvest plays a major role in determining the grain yield, which ensures optimum performance in terms of minimizing grain losses and optimizing grain quality. When harvesting rice, the cutter bar is set as low as feasible to harvest as many of the panicles possible (Personal communication). In general, main stems are taller and produce more grains than primary tillers which in turn are taller and higher yielding than secondary tillers. Hence, adjustment of cutter bar height is an important loss control mechanism. Therefore, to optimize the grain harvest, the cutter bar should be set at optimum height. Further the length of cut crop is directly influenced by the bulk handling capacity of the threshing mechanism. Short crop results in less material and long crop with more material which will affect the overall capacity as well as composition of the grain mixture.

The loss of combine harvester is divided into natural loss (pre harvest loss), platform cutting loss (header loss), threshing loss, cleaning loss and the loss of body (Srivastava, Goering, and Rohrbach *et al.,* 2006), of which the header losses caused by the cutter bar is considered to be important as the header unit is the component which hits the panicles in a vigorous manner. Therefore, the objectives of this study were to measure quantitative loss of grains from the header unit of combine harvester as affected by forward speed and cutting height and to assess the quality of the grains at different cutting heights.

MATERIALS AND METHODS

Study area

This study was accomplished in the field of Farm Mechanization Research Centre (FMRC) in MahaIluppIlama, Anuradhapura, which is situated in Anuradhapura district, North Central province of Sri Lanka.(8°6'381" North, 80°21'1302" East). BW 351 paddy variety was harvested during three weeks of total duration in experimental trial with CLAAS C210 model combine harvester.

Experimental design and treatments
The experiment was conducted to evaluate the effect of combine harvester forward speeds of 2.4, 3.84 and 4.28 km $h^{-1}$with the cutting heights of 10, 15, 20 and 25 cm on header losses of paddy for which a randomized complete block design under split plot arrangement with three replications were used (Table 1). Hence, there were 9 plots in each block. The forward speed was considered as the main plot factor whereas cutting heights were considered as subplot factors. The dimension of each experimental plot was 10m x 4m.

Table 1. Treatment combinations used to evaluate the cutting losses from the combine harvesters

Treatments	No. of level	1	2	3	4
Cutting height (cm)		10 (C1)	15 (C2)	20 (C3)	25 (C4)
Forward speed (km/h)		2.4 (S1)	3.34 (S2)	4.28 (S3)	

Description of CLAAS combine harvester
The header losses were observed using CLAAS C210 combine harvesters equipped with a reel-type header. The CLAAS C210 combine harvester (model *C-210)* of German origin fitted with a 60hp diesel engine, and a 2.1m wide cutter was used. Being a compact and light weight combine harvester equipped with reliable rubber tracks, it is the ideal harvesting machine for wet paddy fields.

Estimation of grain yield
Grain yield was determined by throwing a quadrate made of stiff steel rods measuring 1m 1m x 1m ($1m^2$) area randomly in three sample areas in each plot and the panicles enclosed in such area were harvested manually. The grains were stripped from the panicles manually and the shattering grains from the area was also manually picked up and the total grain yield was estimated using equation 1 as reported by Qamar-uz-Zaman *et al*., (1992).
$Y = (T + L)\ C$ ……………… Equation 1

Where,
Y- Yield of crop (t ha^{-1})
T- kg of grains per m^2
L- kg of shattered grain (pre harvest losses)
C- 10, a constant

Adjustment of forward speed
The combine harvester was adjusted for three speeds such as 2.4 km/h, 3.84 km/h and 4.28 km/h respectively. A stopwatch and a measuring tape was used to measure the time required to pass a fixed distance of 20 m. The time taken to pass this 20m was recorded using a stop watch. This procedure was repeated thrice and the average forward speed was calculated based on the formula given below.

$$Speed = \frac{Driven\ length}{Driven\ time\ period} \text{……………… Equation 2}$$

Measurement of natural losses
A metal frame with an area of $1m^2$ was used to measure natural losses by collecting the grains within the frame area. This was done in five replications in each plot and the average loss per plot was calculated. The quantity of natural loss was calculated and the averaged was obtained.

Adjustment of cutter bar height
As per the treatments, the cutter bar heights were set at 10, 15, 20 and 25cm from the ground in each plot.

Measurement of header losses
The combine harvester was allowed to move forward for about 5m in each plot as per the prescribed treatments. After the combine attained a steady state speed under full load condition, it was suddenly stopped. The header unit was lifted up and the machine was moved back about 2m. The quadrate mentioned above was placed in front of the parked machine. The grains were manually picked up from within the frame placed on the cut swath. Grains were then manually threshed and the header losses were determined by weighing collected grains. The samples for header loss were collected in four replicates from each experimental plot. By subtracting natural loss from collected samples, header loss was obtained (Roy, *et al*., 2001).

$H_L = N_L - C_L$ Where …………………… Equation 3
H_L = Header loss (kg ha^{-1}).
N_L= Weight of both collected grains due to natural loss (kg ha^{-1}).

C_L = Weight of both collected grains and panicles at the back of cutter bar (kg ha^{-1}).

Measurement of cutting height

The cutting height was adjusted according to the treatments by rising/lowering the height of cutter bar, which was again ensured by measuring the height of stubbles in the field after harvesting.

Table 2. Method of measurement of experimental parameters

Parameter	Method of measurement
Cutter bar pulley speed	Tachometer
Diameter of cutter bar pulley	Steel tape
Moisture content of grains before harvesting	Digital moisture meter
Height of cutter bar	Steel tape

Estimation of damaged grain

A weight of 250g of thirty-six grain samples were collected from grain tank and each samples represented 36 plots harvested by the combine harvester. Cracked grains were analyzed by using laboratory crack detector. In order to determine the percentage of cracked grain, three samples of 50 grains were manually husked. The husked paddy grains (brown rice) were put on a crack tester and the number of cracked kernels were recorded. The grain damage was calculated as explained below (Srivastava *et al*.,1995).

$$GD = \frac{W_d}{W_s} x100$$

Where,

GD – grain damage (%)

W_d - weight of damaged grain

W_s -weight of the sample

Data analysis

Data obtained from the field were analysed using SAS version 9.1, while the mean separation was performed using Duncan Multiple Range Test (DMRT) at a significance level of $P < 0.05$.

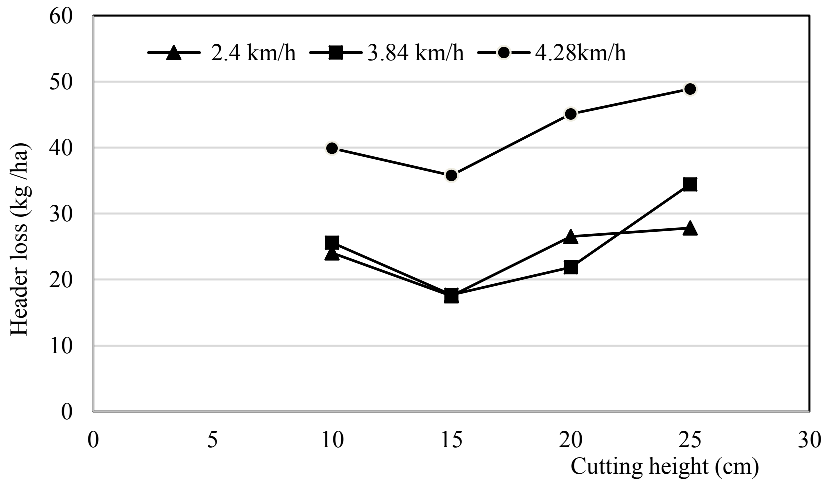
RESULTS AND DISCUSSION

Effect of cutting height on header losses

Header losses across the three levels of forward speed showed a declining trend from 10cm -15cm and increased thereafter. It has been observed that the header losses were lower at 15cm of cutting height, whereas the losses were found to be higher at 10cm, 20cm and 35cm of cutting height (Figure 1). This could be attributed to the large amount of crop harvested at the height of 10 cm due to the increased length of the plant stalks resulting plant jam in front of the cutter which led to loss of the grains on the ground which consequently increased the header losses.

Further, the increased losses at cutting heights of 20cm and 25cm could be explained that the paddy bushes grow about 1m height and the panicle start to grow from 75cm from ground which varies from variety to variety. When the cutter bar height is increased, it is difficult to cut the panicle from the plant completely. Hence, some parts of panicle remain in the plant itself which is also considered as losses.

Figure 1. Header losses at various forward speeds



It is evident that the yield loss due to header losses increased from 0.19% - 0.32% at the cutting height of 10cm, 0.14% - 0.29% at the cutting eight of 15cm, 0.21% - 0.36% at 20cm and 0.22% - 0.39% at the cutting height of 25cm. However, the yield losses were comparatively greater at 25cm. It was clearly observed that the header losses were less than 0.3% at the cutting height of 15cm (Table 3).

Table 3. Mean header losses across the different cutting heights

Cutting height (cm)	Forward speed (km/h)	Header loss	
		kg/ha	as % yield loss
	2.40	24.02	0.19
10	3.84	25.57	0.20
	4.28	39.87	0.32
	2.40	17.68	0.14
15	3.84	17.68	0.14
	4.28	35.77	0.29
	2.40	26.49	0.21
20	3.84	21.84	0.17
	4.28	45.11	0.36
	2.40	27.81	0.22
.25	3.84	34.43	0.28
	4.28	48.88	0.39

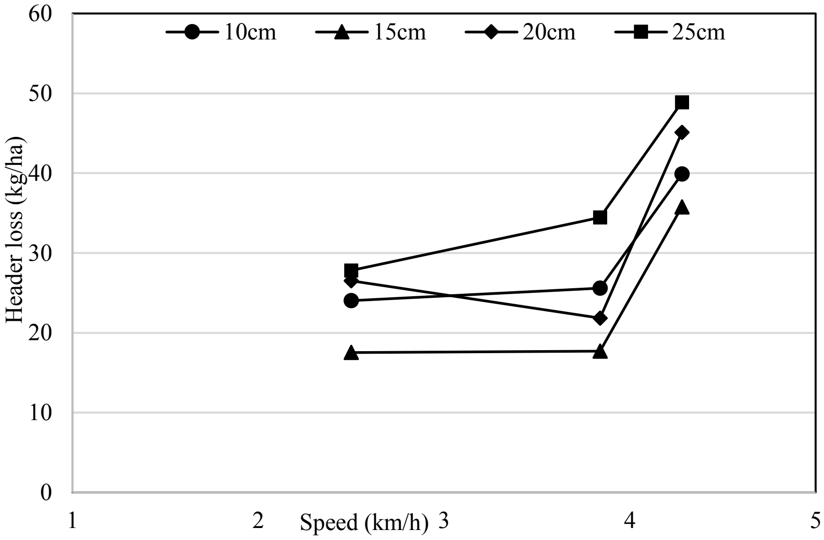
Cutting height is considered from two different aspects. The stems are cut while reel bend the stems towards the cutter bar. At increased cutting heights the plants tend to bend more which in turn leads to more grain loss because of vibration. From another perspective, the stem gets thinner towards the upper parts in the stem. At increased cutter bar heights, crops with lower height cannot be cut by the cutter bar and seeds drop when they get in contact with reel. It was reported that for minimum cutting losses, reel should be placed in 15-25 cm above the cutter bar and the height should be lower than low height of crop (Arman Jalali, and Reza Abdi, 2014). The thicker stems in lower cutting heights resist more against the cutting bar and endure higher vibration which results in grain loss. This means that the cutting heights should be in optimized range (Mcneil *et al*., 2009). Crops with low height couldn't be cut by a cutter and seeds drop when they contact with the reel.

Greater and distinct header losses were observed at the forward speed of 4.28 km/h at all the four levels of cutter bar heights. Header losses at 2.4 km/h and 3.84 km/h were lower compared to that at the forward speed of 4.28km/h. It was found out that header losses were lower at 15cm of cutting height across the three levels of operating speeds (Figure 1).

Effect of forward speed on header losses

Forward speed plays an important role during harvest process in determining the proportion of harvest losses as it has negative impact in the process of harvest because losses proportionate with the speed of harvester due to its impact on the operating units and feeding rate (Al-Kazaz, 1990, Al-Tahhan *et al*., 1990, Barać *et al*., 2011, Chen *et al*., 2012). The effect of forward speed on header losses at different cutting height showed a declining trend at the beginning and thereafter the losses were found to be increased as the forward speed increased at all the four levels of the cutting height. Results indicate that, rate of losses were very high with a cutting height of 25cm and that was lower at the cutting height of 15cm above ground surface, where, the average of length plants was 100cm (Figure 2).

Figure 2. Header losses at different cutting height



Maximum of grain losses of 48.8 kg/ha, 45.1 kg/ha, 39.8 kg/ha and 35.7 kg/ha were recorded at forward speed of 4.28 km/h and cutting height of 25, 20, 10 and 15cm respectively. The forward speeds of 2.4 and 3.84 km/h resulted in lowest grain losses of 17.52 and 17.68 kg/ha respectively at 15cm of cutting height, which was found to be increased to 35.7 kg/ha at the same cutting height.

However, in general all the treatments showed an increasing trend in header losses with respect to the increase in forward speed from 2.4 to 4.28 km h^{-1} across all the four levels of cutting height. It is evident that more vibration occurred with increasing forward speed in the header unit of the combine harvester. Furthermore, the mismatch between the speed of the reel and the forward speed of the combine harvester has also led to increased scattering of grain from the spikes which is in accordance with findings of Stephen (1981) who reported that found that grain losses in the cutting, threshing, separation, and cleaning units increase with increasing forward speed of the Massey Ferguson and Laverda combine harvesters. These results could be attributed to the large number of moving parts in the header such as the reel which constitute a large proportion of the losses in the header. Decreasing reel rotational speed compared to the harvester forward speed lead to push dry spikes forward, breaking it, and fall some of them to the ground which increases the proportion of losses (Ramadan 2010).

The lower forward speed of 2.4 km/h resulted in 0.19%, 0.14%, 0.21% and 0.22% of header losses at 10, 15, 20 and 25 cm cutting heights respectively. However, greater header losses as percentage of yield loss were observed as 0.32%, 0.29%, 0.36% and 0.39% at 10, 15, 20 and 25 cm cutting heights respectively. This clearly shows the increasing trend in header losses as the forward speed increased (Table 3). The highest value was 0.39 % accomplished by higher forward speed of 4.28km/h at 25cm cutting height whereas it was 0.14% for the lower forward speed of 2.4 km/h at the cutting height of 15cm which is in accordance with the findings of Kamel, 1999. Increasing forward speed led to increase in the header loss proportions of combine harvester's header unit.

The above findings coincides with the findings of many researchers of which Ali *et al*., (1990) studied a self-propelled rice combine harvester and reported that raising travel speed from 0.8 to 2.9 km/h increased grain losses. Qarnar-uz-Zaman (1992) showed the losses increased with increasing ground speed. The reel speed should be adjusted about 1.25- 1.5 of ground speed. Junsiri and Chinsuwan (2009) showed that head grain loss increased with increase in reel rotational speed. Mansoori and Minaee (2003) studied the effect of forward speed on header loss and indicated that header loss increased with increasing ground speed. The ground speed of the combine showed the greatest loss related to maximum ground speed. The lowest rate of loss related to minimum ground speed.

The effect of cutting height and speed on header losses were highly significant ($P < 0.01$). This suggests the influence of the factors on header losses. However, there was no interaction between the cutting height and the operating speed (Table 4.) Header losses were significantly affected by the cutting heights across the three forward speeds evaluated.

Table 4. Analysis of variance of header losses

Source	DF	MS	F	P
Block	2	19.3	0.47	0.63
Cutting height (H)	3	271.3	5.69	0.0042
Speed (S)	2	1296.8	31.48	< 0.0001
H x S	6	21.9	0.53	0.776

The effect of cutting height was highly significant on total header loss. The cutting height of 25 cm gave significantly greater header loss of 37.04 kg/ha accompanied by the significantly lowest header losses of 23.66 kg/ha at the cutting heights of 15 cm. There were no significant differences in the header losses at the cutting heights 10 and 15cm as well as 20 cm and 25cm (Table 5).

Table 5. Effect of cutter bar heights and combine forward speed on header losses

Cutting height (cm)	Header losses (kg/ha)
10	29.82 bc
15	23.66 c
20	31.14 ab
25	37.04 a
Speed (km/h)	
2.40	23.96 b
3.84	24.88 b
4.28	42.41 a

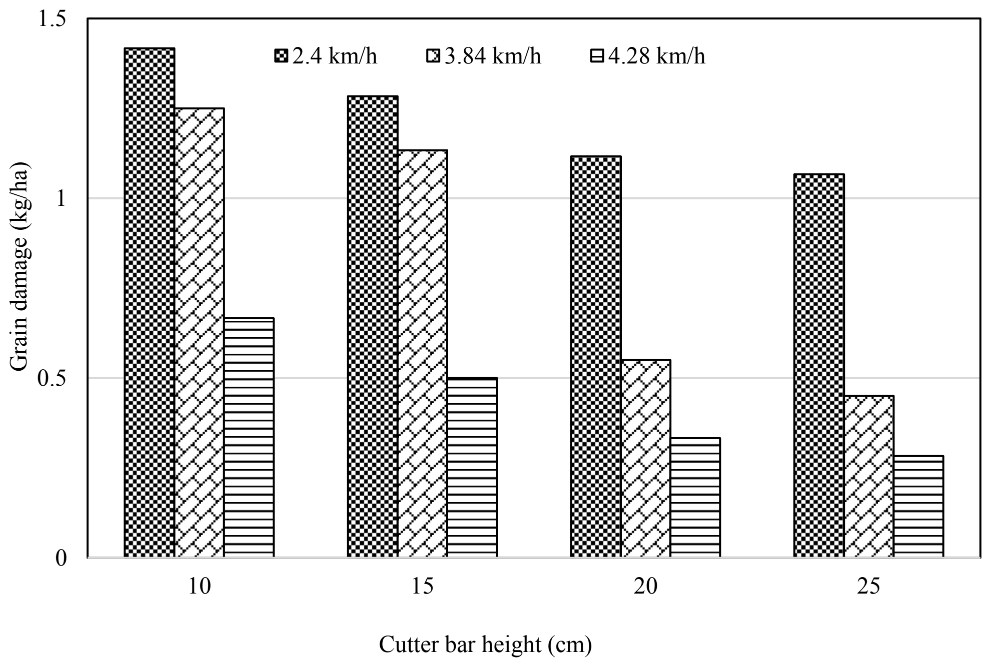
Means with the same letter are not significantly different at P = 0.05

The forward speed of 4.28 km/h had significantly highest loss of 42.41 kg/ha, whereas significantly lowest loss of 23.96 kg/ha was associated with the forward speed of 2.4 km/h and at 3.84 km/h which were not significantly different from each other.

Grain damage

A distinct relationship has been found out between the cutting height and the damaged grains across the forward speeds tested. However, it has been found that in addition to the cutting height, the grain damage was affected by the feed rate of the combine as well as the moisture content of the grains as there was a clear reduction in the amount of damaged grains per hectare as the forward speed increased. Cutting heights from 10 cm – 25 cm resulted in 1.41 – 1.06 kg/ha at the forward speed of 2.4 km/h, 1.25 – 0.45 kg/ha at the forward speed of 3.84 km/h and 0.66 – 0.28 kg/ha at the forward speed of 4.28 km/h (Figure 3).

Figure 3. Effect of cutter bar height on grain damage



At increased forward speeds of the combine, the feed rates are higher. Therefore, more crop material is taken into the combine so that a dense layer of material passing between cylinders and concave bars at high feed rates which provide more production and reducing the repeated impacts by the cylinder bars (Helmy *at al*., 1995; Vas and Harrison, 1969; Caspers 1966 and Bainer *et al*., 1960). As a result of this, the grains were prevented from the higher impact velocity of the drums due to the cushioning effect of the grains at the forward speed of 4.28 km/g and hence the grain damage was lower.

The grain damage also showed a declining trend as the cutting height increased from 10cm – 25cm. At lower cutting heights, large amount of crop is harvested due to the increased length of the plant stalks resulting clogging of the panicles in front of the cutter bar which also could have led to the damage of the grains which consequently decreased the grain quality. Therefore the grain damage declined with respect to the increase in cutter bar height. Total grain damage contains visible grain damage and invisible grain damage that is reducing the quality of grain as it leads to a reduction in the percentage of germination.

It has also been documented that the impact of the combine design and the technological parameters of the threshing apparatus had the greatest impact on the grain damage (Feiffer *et al*., 2005). Mansoori and Minaee, 2003 found that an increase in cylinder concave clearances results in less breakage of grain. In addition, increasing cylinder rotational speed from 750 to 950 rpm would double grain breakage (Mansoori and Minaee, 2003 and Sabir *et al*., 2005). It has also been reported that the grain moisture, cylinder speed and feed rate had significant effect on mechanical damage inflicted upon the grain during combine harvesting (Arvinder *et al*., 2001).

Moreover, it has been documented that the grains have lower flexibility or strength against the impact force at low grain moisture contents and therefore the grain is more prone to breakage when it is beaten (Chinsuwan *et al*., 2003). This result was also reported by Askari Asli-Ardeh and Abbaspour-Gilandeh, (2008) and Sabir *et al*. (2005) for paddy threshing by a head feeding thresher.

Therefore, the observed grain damage could be the multiple effect of grain moisture with variations in impact velocity of the threshing drum. However, it was observed that there were differences in grain moisture content within panicles and also differences between different parts of the field which lead to great variation in the grain damage. Therefore, the tip velocity of threshing drum, varietal strength and the grain moisture content might also have caused the differences in grain damage regardless of the cutting heights.

The effect of forward speed of the combine harvester on grain damage is significant at $P = 0.05$. The cutting height did not have any significant impact on grain damage. Further, there were no interaction between the cutting height and forward speed (Table 6).

Table 6. Analysis of variance of grain damage

Source	DF	MS	F	P
Block	2	0.093	1.54	0.24
Cutting height (H)	3	0.086	1.43	0.27
Speed (S)	2	1.420	23.53	< 0.0001
H x S	6	0.044	0.74	0.62

The forward speed of the harvester had significant effect on decreasing the grain damage (Table 7). Grain damage decreased from 1.14 kg/ha to 0.45 kg/ha as forward speed increased from 2.4 to 4.28 km/h. This trend of decreasing grain damage might be due to increasing feed rate which created cushioning effect resulting in less impact force on the individual kernels and hence less grain damage. The decrease in grain damage with an increase in feed rate has also been documented by Sabir *et al*., (2005).and Vas and Harrison (1969).

Table 7. Effect of forward speed on grain damage

Speed (km/h)	Grain damage (kg/ha)
2.40	1.14 a
3.84	0.84 b
4.28	0.45 c

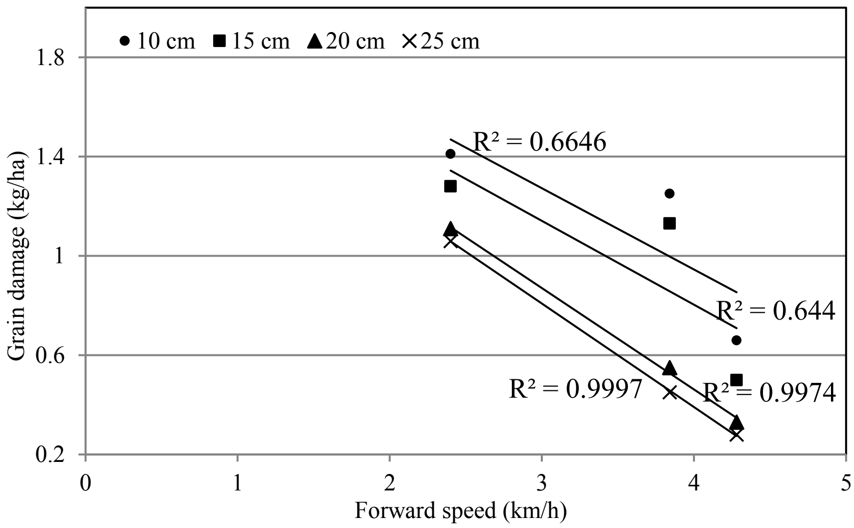
Means with the same letter are not significantly different at $P = 0.05$

Table 8 also reveals that all the three levels of the forward speeds are significantly different from each other at $P = 0.05$. The forward speed of 4.28 km/h resulted in significantly lower grain damage of 0.45 kg/ha whereas significantly greater damage of 1.14 kg/ha was observed at the forward speed of 2.4 km/h.

Relationship between grain damage and combine forward speed

It has been observed that a negative relationship exists in between the combine forward speed and the grain damage. Moderate relationships of R^2= 0.66 and R^2=0.64 were obtained between the forward speed and the grain damage at cutting heights 10 cm and 15 cm respectively, whereas there was a strong negative relationship between these variables (R^2= 0.99) at 20 cm and 25 cm cutting heights (Figure 4).

Figure 4. Relationship between the combine forward speed and grain damage



This refers that about 66% and 64% of the variation in grain damage is only due to the effect of forward speed at cutting heights 10cm and 15 cm. Thus the remaining 34% and 36% of the variations at these cutting heights could be accounted by the varietal characteristics, variations in the moisture contents of the grains and the impact of tip velocity of the threshing drum. However, about 99% of the variation in grain damage at cutting heights 20cm and 25cm was accounted by the effect of forward speed and only 1% is addressed by the other factors.

CONCLUSIONS

- Increased length of the plant stalks resulted plant jam in front of the cutter bar which led to loss of the grains on the ground which consequently increased the header losses at 10 cm cutting height. Difficulties in cutting the panicle from the plant completely at cutting heights of 20 cm and 25 cm led the panicles in the plant itself which was also considered as header loss. Consequently, the header losses were higher at the cutting heights of 10, 20 and 25 cm. However, header losses were less than 0.3% at the cutting height of 15cm.

- More vibration in the header unit at increasing forward speed of the combine harvester and the mismatch between the speed of the reel and the forward speed of the combine harvester have also led to increased shattering of grain from the panicles. Hence, all the treatments showed an increasing trend in header losses with respect to the increase in forward speed from 2.4 to 4.28 km/h across all the four levels of cutting height.

- Grains were found to be prevented from the higher impact velocity of the drums due to the cushioning effect of the grains at the forward speed of 4.28 km/h and hence the grain damage was lower. Further, the damage also showed a declining trend as the cutting height increased from 10cm – 25cm. A negative relationship exists in between the combine forward speed and the grain damage of which there was a strong negative relationship between these variables (R^2= 0.99) at 20 cm and 25 cm cutting heights.

REFERENCES

Ali, A., Majid, A. and Rehman, H. and Sagar, M.A. 1990. Milling recovery of Basmati as affected by threshing methods and crop harvesting time. *Pakistan J. Agric. Res*. 11: pp 7-12.

Al-Kazaz, K.M.A. 1990. Impact of harvester speed on the losses proportion of the mechanical harvest. Iraqi Journal of Agricultural Science, Volume 21

Al-Tahhan, Y.H., Saeed, S.M., and Abdul- Jabbar. S. 1990. Impact of forward speeds of the harvester in the amount of losses in the wheat in the Al-Jazeera region. Nineveh, MesopotamiaJournal of Agriculture.

Arman, J., and Reza, A., 2014. The Effect of Ground Speed, Reel Rotational Speed and Reel Height in Harvester Losses." Journal of Agriculture and Sustainability 5.2.

Arvinder, S., Garg, I.K., Sharma, V.K and Singh, A. 2001. Effect of different crop and operational parameters of a combine on grain damage during paddy harvesting. *J.Res.Punjab Agric. University,* 38: pp 241–252.

Askari Asli-Ardeh, E. and Abbaspour-Gilandeh, Y. 2008**.** Investigation of the effective factors on threshing loss, damaged grains percent and material other than grain to grain ratio on an auto head feed threshing unit. *American Journal of Agricultural and Biological Sciences*. 3(4): pp 699- 705.

Bainer, R., Kepner, R.A. and Barger, E.L. 1960. Principles of Farm Machinery. Wiley and Sons, New York. pp 381-410.

Barać, S., Vuković, A. Milenković.,Biberdžić. M.,Mand A., Dimitrijević. 2011. Qualitative analysis of wheat combine harvester work Effects in rye harvest. Research Journal of Agricultural Science, 43 (1)273-28

Bawatharani,R., Jayatissa, D.N., Dharmasena, D. A. N. and Bandara. M. H. M. A "Impact of reel index on header losses of paddy and performance of combine harvesters." (2013).

Caspers, L 1966. Influence of concave clearance and construction on threshing performance. *Transactions of the ASAE* 16(6): pp 220-226.
Chen, D., F. Kang, Q. Zhu, and S. Wang. 2012. Study on combine harvester speed control based on optimum threshing power consumption mode. Applied Mechanics and Materials. 130-134, pp 1911-1914.
Chinsuwan, W., Pongjan, N., Chuan-Udom, S., and Phayom, W. 2003. Effects of Feed rate and Threshing Speed on Performance of Axial Flow Rice Thresher. *TSAE Journal*. 10(1): pp 9-14.
Feiffer, A., Feiffer P., Kutschenreiter, W., and Ramachander, T. 2005. *Getreideernte – sauber sicher, schnell* Verlag DLG. Pp 224. In: *Agronomy Research* **6** (Special issue): 367–376, 2008.
Helmy, M.A., Gomaa, S.M., Hindey, F.I. and Abushieshaa, R.R. 1995. Comparative study on two different rice combine harvesting machine. Misr. J.Agric. Eng. 12(2): pp 479-495.
Junsiri, C., and Chinsuwan, W. 2009 (a). Operating parameters affecting header losses of combine harvesters for Chainat 1 rice variety. KKU Research journal 14 (3): pp 314-321.
Kamel, O.M. 1999. Rice harvesting losses utilizing two different harvesting techniques of Japanese combine. Misr J. Ag. Eng., 16 (4): pp 237-251.
Mansouri, H., and S. Minaei, 2003. "Assessment of Machine Parameters Effect on Wheat Loss in Combine JD 955." Abstract of Paper on First National Conference of Assessing Agricultural Crops Wastes. Agricultural Faculty of Tarbiat Modaress University. Tehran, Iran.
Mcneil, S., Montross, M., and Overhults, D. 2009. A Comprehensive Guide to Wheat Management in Kentucky. University of Kentucky, Collage of Agriculture, Lexington, KY, 40546.
Qarnar-uz-Zaman, A., Chaudhry,D., AsgharRana,M., 1992. "Wheat harvesting losses in combining as effected by machine and crop parameters." Pakistan Journal of Agricultural Science 29(1): 1-4.
Ramadan, G. M. 2010. Effect of forward speeds for two types of combines on quantity loss of wheat. Journal of Tikrit University for Agriculture Sciences (JTUAS). 10(1): 247-254. (In Arabic).
Roy, S.K., Jusoff, K., Ismail, W.I.W., Ahmad, D 2001. Performance evaluation of a combine harvester in malaysian paddy field. Paper presented at Asia Pacific Advanced Network (APAN) Penang Meeting, University Science Malaysia (USM), Penang, Malaysia, August 20-22.
Sabir, M.S.,Iqbal, M.,and Yasin. M.2005. Influence of selected combine and crop parameters
Srivastava, A.K., Goering, C.E. and Rohrabach, R.P. 1995. Engineering Principles of Agricultural Machines. ASAE- Text Book Number 6. Published by American Society of Agricultural Engineers. Pamela Devore-Hansen, Editor, Books & Journal. USA.
Srivastava, Ajit, K., Carroll, E., Goering, Roger, P., Rohrbach, and Dennis, R. 2006. Grain harvesting. Chapter 12 in Engineering Principles of Agricultural Machines, 2nd ed., 403-436. St. Joseph, Michigan: ASABE. Copy right American Society of Agricultural and Biological Engineers.
Stephen, D.H. 1981. Combine losses compared. Power Farming Magazine. 60 (9):28-29.
Vas, F.M. and Harrison, H.P. 1969. The effect of selected mechanical threshing parameters on kernel damage and threshability of wheat. Canadian Agricultural Engineering. 11(2): pp 83-87.

R.Bawatharani
Department. of Agric. Engineering
Faculty of Agriculture, Eastern University, SRILANKA
Email: bavatharani@yahoo.com.sg

M.H.M.A.Bandara
Department of Agriculture, Peradeniya, SRILANKA
Email:mhmabe@yahoo.com

D.I.E Senevirathne
Department. of Agric. Engineering
Faculty of Agriculture, Eastern University, SRILANKA
Email:ireshsenvirathne@gmail.com