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An investigation of the amount of grain loss – using plant density and reel index of two popular brands of combine harvesters

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Abstract. Large wheat fields are cultivated in Iraq every year, especially in the Bazalan region. Although the grain production rate is high in Bazalan, the grain harvest loss is significant. Investigating wheat crop losses in different harvesting units is crucial to making decisions and improving working conditions. The current research was carried out to study the effect of the two popular brands of combine harvesters (New Holland TC56 and John Deere 1450 CWS) based on a relationship between the amount of loss from combine harvesters, reel indexes, and plant density. Three reel indexes (1, 1.5, and 2) and two plant densities (high-density and low-density sites) were considered. A randomised complete block split-plot design with three replications was carried out. The results showed positive superiority of the New Holland TC56 in the percentage of header losses, threshing losses, separation and cleaning losses, total harvest loss, and total loss with the highest performance efficiency of 97.725%; however, the harvester performance efficiency of the John Deere 1450 CWS remained within the acceptable loss limits. Finally, the best results were achieved with a 1.5-reel index level interacting with a high-density site; these results were statistically more significant than the differences between the New Holland TC56 and the John Deere 1450 CWS.

Key words: combine harvester, harvester efficiency, header losses, plant density, wheat.

INTRODUCTION

The Bazalan-Duhok region in the northern governorate of Iraq relies heavily on agriculture for its economic existence. A large number of farmers are engaged in wheat production, and about 7,000 ha are planted with wheat (Center Statistical Organization, 2019). Presently, wheat production has become a serious issue for investors and farmers in Iraq, especially in the Bazalan region, due to climate change, different farming systems, and a shortage of skilled labour (FAO, 2021).

One of the solutions in large-scale wheat areas is that farmers and investors have increased the utilisation of combine harvesters (Kadhim, 2018). Therefore, Iraqi wheat harvesting has improved and witnesses continuous growth in harvesting patterns. In the recent past, this developed from manual labour into harvesting machines; now, a combine harvester is acceptable because of a notable change in the social structure in rural areas. A combine harvester provides comfort, reduces labour and harvest loss, and provides a higher percentage of wheat cultivation with a decreased harvest cost and less wastage of agricultural energy; however, the loss of wheat yield is still a significant problem that seriously affects the profitability of the wheat crop (Ali & Jabara, 2021). Various critical technical parameters influence harvester performance; some are related to plants, and the others are related to harvesting machines (Šotnar et al., 2018; Derevjanko et al., 2020). Wang et al. (2021) clarified that the most important reason for this loss in harvest is the incorrect selection of the reel index while loss differences are owed to the density and type of planting. Further, Tihanov et al. (2021) found that wheat crop losses are due to improper adjustment of a harvester for different wheat crop conditions and farming systems. In fact, Bawatharan et al. (2013) and Zubko et al. (2018) stated that the amount of loss and the reasons for such loss occur as per inappropriate modifications of operating conditions, which is a result of users lacking the needed technical proficiency; consequently, the reel index, plant density, and combine harvester brand affects wheat harvest. Hence, this implies to the need to further investigate such relationships; in the Bazalan region, these factors have not been thoroughly studied.

A perfect setup of a combine harvester is the most crucial prerequisite for reducing the amount of harvest loss. Though combine harvester manufacturers provide recommended settings for each crop, these settings are based on average crop yield and average plant conditions. Therefore, the main objective is to study the effect of two popular brands of combine harvesters (New Holland TC56 and John Deere 1450 CWS) based on a relationship between levels of reel index and plant density on a percentage of header, threshing, separation and cleaning losses, total harvest loss, total loss, and harvester performance efficiency.

MATERIALS AND METHODS

Study area specifications

The field test was conducted at Bazalan in the Dahuk governorate of Iraq. Bazalan coordinates 36°49'14.2"N 42°53'02.0"E and monthly weather averages are shown in Fig. 1.

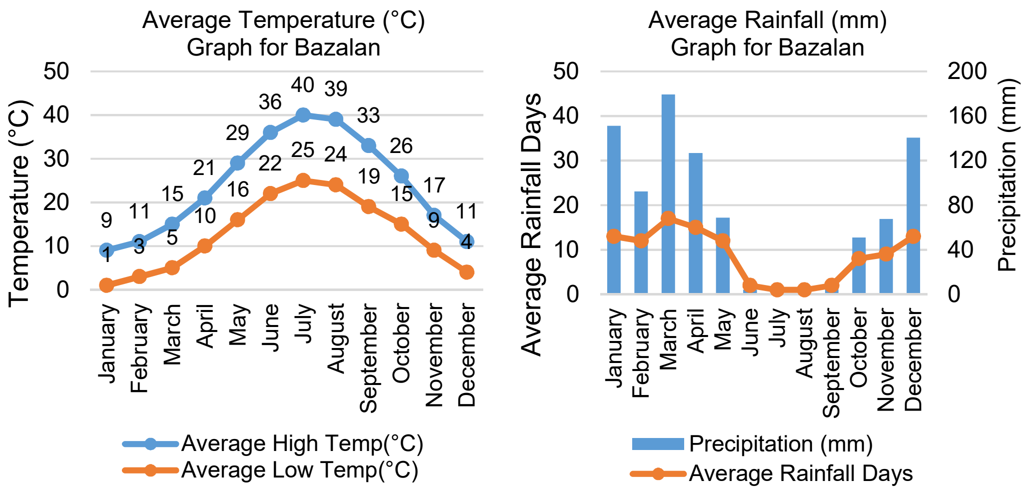

Figure 1. Bazalan climate weather (World weather, 2022).

Treatments and Statistical Design

A randomised complete block split-plot design with three replications was used to estimate the significant impact of reel index, plant density, and types of combine harvesters on wheat harvesting losses. The treatments were arranged so that the plant density was considered as the main plot factor with two plant densities. In the high-density site, the average number of spikes per square metre was 310 spikes and the average height of the crop was 50 cm; the average number of spikes in the low-density site was 186 spikes of various sizes and there was an average crop height of 30 cm. Types of combine harvesters were considered as subplot factors; the models were the New Holland TC56 combine harvester (model 2007) and the John Deere 1450 CWS combine harvester (model 2004). Table 1 presents the specifications of these combine harvesters.

Table 1. Specifications of combine harvesters used in the experiment (John Deere, 2007; New Holland, 2007)

Specifications	John Deere 1450 CWS	New Holland TC56
Brand	John Deere	New Holland
Model	1450 CWS	TC56
Years of production	2004	2007
Engine type (model / version)	Power TECH PVX 6068 HZ	6.75T
Engine capacity	6,788 cm3 (6.8 l.)	7,474 cm3 (7.5 l.)
Cylinders, qty	6	6
Power	132 kW / 180 KM	114 kW / 155 KM
Header width (working)	485 cm	457 cm
Alternative widths	365–580 cm	366–518 cm
Diameter of cylinder threshing mechanism	61 cm	60 cm
Width of cylinder threshing mechanism	130 cm	130 cm
Length (with header)	7.9 m	9.32 m
Width (with header)	4.9 m	4.9 m
Width (without header)	3.65 m	3.37 m
Height (with cab)	3.98 m	3.8 m
Total weight (with cab)	10,500 kg	9,700 kg

The farmer should consider the effect of the reel index value on the geometrical form of the reel tine bar trajectory and its implications on reel performance. The reel index is an often used parameter in the analysis of reel motion and performance. The reel index is denoted by equal to ωR/V or R/R0 where R0 = V/ω and the limits of R0 are $0 < R0 < R$. It should set the theoretical limits of the reel index to be $1<K<\infty$. The suitable value of this index should vary with the crop and crop conditions; the ground speed of the harvester was stable to obtain the three levels required for the reel index, which are 1, 1.5, and 2. The reel index was calculated according to the equation described in Oduori et al. (2012):

$$\text{Reel index} = \frac{\text{Reel angular velocity } (rad\ s^{-1}) \cdot \text{ radius of a reel } (m)}{\text{Header advance velocity } (m\ s^{-1})} \quad (1)$$

Measurement of wheat crop losses

Wheat yield losses were determined using the methods given in Eqs 2 to 6:

1 – Percentage of pre-harvest losses (Natural loss): The natural loss was estimated using a 65 cm × 38.5 cm frame before combine harvesters entered the field.

The frame was placed in 10 random places. Then, the percentage of pre-harvest losses was calculated from the equation proposed by Hamzah & Alsharifi (2020).

2 – Percentage of header losses: The header loss was estimated using three 65 cm × 38.5 cm frames at the end of each harvested row. The frames were placed at one-third of the left, middle, and right header length. Kernels and ears were finally gathered to be counted, and the method described in Jalali & Abdi (2014) was used to calculate the header loss from the following equations (2 and 3):

$$Header\ loss = (Total\ grains\ at\ the\ head - Total\ grains\ counted\ in\ the\ pre\ harvest\ losses) \text{x1,000grain weight x } 4\text{x}10^{-2} \quad (2)$$

$$Percentage\ of\ Header\ loss = \left(\frac{Header\ loss}{Total\ field\ production}\right)\text{x100} \quad (3)$$

3 – Percentage of threshing losses: Threshing losses are those unthreshed grain heads that escape the combine at the rear with the straw. Threshing losses can be expressed as a percentage from the equation described by Hamzah & Alsharifi (2020):

$$Percentage\ of\ threshing\ losses = \left(\frac{Mass\ of\ unthreshed\ grains}{total\ mass\ of\ grains}\right)\text{x100} \quad (4)$$

4 – Percentage of separation and cleaning losses: Separation and cleaning losses are lost grain with straw expressed as a percentage of total grain entering the combine (Srivastava et al., 2006).

5 – Actual productivity: The actual productivity was calculated via collecting the grains from the unloading auger before dropping them into the tank for a distance of 15 metres and all the experimental treatments.

6 – Total yield: The total yield of the crop kg/dunam was calculated by summing the following:

$$Total\ yield = \text{Net yield inside the harvester tank} + \text{Total harvest loss} + \text{pr} - \text{harvest losses} \quad (5)$$

7 – Harvester performance efficiency:

$$Harvester\ performance\ efficiency = \frac{Net\ yield}{Net\ yield + Total\ harvest\ loss}\text{x100} \quad (6)$$

RESULTS AND DISCUSSION

The natural loss percentage in the high-density site was 1.14 and 1.32% and in the low-density site was 1.39 and 1.74% for the New Holland TC56 and John Deere 1450 CWS, respectively. The difference between these values is due to a difference in the actual product to the plant density, where the productivity of the New Holland TC56 harvester was 470.58 and 272.64 kg per dunam[1] while the productivity of the John Deere 1450 CWS harvester was 408.33 and 218.27 kg dunam^{-1} for the high-density and low-density sites, respectively.

[1] A dunam equals 2,500 square metres.

Effect of plant density on wheat harvest loss and harvester efficiency

Table 2 shows the effect of plant density on the percentage of header losses, threshing losses, separation and cleaning losses, total harvest loss, total loss, and harvester performance efficiency, respectively. The results for the effect of plant density showed statistically significant differences in all the studied traits. The header losses recorded the highest considerable loss, which was negatively reflected on the total harvester loss and the efficiency of the harvester performance. The superiority of the dense field, with the lowest percentage of loss over the low-density area, is due to the short length of the plants; meanwhile, an increase of hammering on the spikes increases the rate of loss in the low-density field, as presented in Table 2. The difference in the loss ratios between the high-density site and the low-density site was 5.62, 0.178, 0.757, 6.538, 6.871, and 5.305% for the header, threshing, and separation and cleaning losses, total harvest loss, total loss, and harvester performance efficiency, respectively. These results are consistent with the theory that a function of plant density has a significant influence on percentage losses (Kviz et al., 2015; Manzoor et al., 2021; Wang et al., 2021).

Table 2 The impact of planting density on percentage losses in wheat harvesting and efficiency of the harvester

Plant density	*Percentage of header losses, %	*Percentage of threshing losses, %	*Percentage of Separation and cleaning losses, %	*Total harvest loss, %	*Total loss, %	**Harvester performance efficiency, %
High-density site	3.69 b	0.726 b	1.598 b	6.024 b	7.258 b	94.372 a
Low-density site	9.31 a	0.904 a	2.355 a	12.562a	14.129a	89.067 b

*The lowest values are the best; **The highest values are the best, the similar letters mean that there is no significant difference at the level of 5%.

Effect of combine harvester types on wheat harvest loss and harvester efficiency

The percentage of losses showed a significant difference between the two types of combine harvesters in the harvesting operation. The use of the New Holland TC56 harvester provided the lowest loss value and the best performance among harvesters, with a percentage of 3.928, 0.416, 1.096, 5.44, 6.71, and 94.893% of header losses, threshing losses, separation and cleaning losses, total harvest loss, total loss, and harvester performance efficiency, respectively (Table 3). Header losses, threshing losses, separation and cleaning losses were significantly influenced by the John Deere 1450 CWS harvester (Table 3). The cutting unit of the John Deere 1450 CWS harvester was associated with a possible deficiency in cutting height control. It generated a nonhomogeneous cut, causing the most significant wheat harvest loss, especially for the header losses of 9.075%. It was reflected in the total harvester loss and then in the efficiency of the harvester performance. According to Xavier et al. (2020), studies on the types of combine harvesters promote operation improvements and reduce costs; it has a greater influence on the percentage losses due to the reduced collection capacity and higher losses of the product in the field.

Table 3. The impact of combine harvesters on percentage losses in wheat harvesting and efficiency of the harvester

Types of combine harvesters	*Percentage of header losses, %	*Percentage of threshing losses, %	*Percentage of Separation and cleaning losses, %	*Total harvest loss, %	*Total loss, %	**Harvester performance efficiency, %
New Holland TC56	3.928 b	0.416 b	1.096 b	5.44 b	6.71 b	94.893 a
John Deere 1450 CWS	9.075 a	1.214 a	2.857 a	13.146a	14.678a	88.546 b

*The lowest values are the best; **The highest values are the best, the similar letters mean that there is no significant difference at the level of 5%.

Effect of reel index on wheat harvest loss and harvester efficiency

The results showed that the effect of the reel index has statistically significant differences in the percentage of header losses, threshing losses, separation and cleaning losses, total harvest loss, total loss, and harvester performance efficiency (Table 4). The percentage of header losses recorded the highest significant loss.

A reel index level of 1.5 is superior in having the lowest rate of loss when compared to a reel index level of 1 or 2. In the reel index of 1 (lower values), the losses were 6.929, 0.931, 2.091, 9.951, 11.352, and 91.189%. In comparison, in the reel index of 2 (higher values), there were increased losses, which were 7.287, 0.777, 2.174, 10.238, 11.639, and 90.894% of header losses, threshing losses, separation and cleaning losses, total harvest loss, total loss, and harvester performance efficiency, respectively, as presented in Table 4.

Table 4. The impact of reel index on percentage losses in wheat harvesting and efficiency of the harvester

Reel index	*Percentage of header losses, %	*Percentage of threshing losses, %	*Percentage of Separation and cleaning losses, %	*Total harvest loss, %	*Total loss, %	**Harvester performance efficiency, %
1	6.929 b	0.931a	2.091 b	9.951 a	11.352a	91.189 b
1.5	5.289 c	0.737 b	1.664c	7.69b	9.091b	93.074 a
2	7.287 a	0.777 b	2.174 a	10.238a	11.639a	90.894 c

* The lowest values are the best; **The highest values are the best, the similar letters mean that there is no significant difference at the level of 5%.

In a reel index value of 1, due to the low speed of the reel in relation to the ground speed of the harvester, the spikes are pushed forward and break in front of the cutting knife. A 2-reel index means a high speed of the reel in relation to the ground speed of the harvester; this causes the fans to hammer more on the spikes and break or loosen them, leading to an increase in the quantitative loss of the yield. These results are consistent with Fadavi et al. (2017) and Chaab et al. (2020).

Effect of the interaction between the planting density and the combine harvesters on wheat harvest loss and harvester efficiency

Table 5 shows statistically significant differences in the effect of the interaction between crop density and type of combine harvester in percentage losses in wheat harvesting and harvester performance efficiency. The high-density site showed the lowest loss ratio for both harvesters, outperforming the low-density site. The increase of the plant density led to the decrease of the total harvest loss for the New Holland TC56 and John Deere 1450 CWS; the results were 3.642 and 8.406% in high-density sites and 7.237 and 7.237% in low-density sites, respectively. Because of the density and length of the plant, the engineering design of the machine matched the plant density.

Table 5. The impact of the interaction between the planting density and the combine harvesters on percentage losses in wheat harvesting and efficiency of the harvester

Plant density	Types of combine harvesters	*Percentage of header losses, %	*Percentage of threshing losses, %	*Percentage of Separation and cleaning losses, %	*Total harvest loss, %	*Total loss, %	**Harvester performance efficiency, %
High-density site	New Holland TC56	2.523 d	0.273c	0.846 d	3.642 d	4.79 d	96.495a
	John Deere 1450 CWS	4.877 c	1.179a	2.349 b	8.406 b	9.728 b	92.249c
Low-density site	New Holland TC56	5.333 b	0.558b	1.346 c	7.237 c	8.631 c	93.291b
	John Deere 1450 CWS	13.274a	1.249a	3.363 a	c	19.627a	84.843d

*The lowest values are the best; **The highest values are the best, the similar letters mean that there is no significant difference at the level of 5%.

The results showed significant superiority of the New Holland TC56 over the John Deere 1450 CWS. It is clear that the New Holland TC56 harvester was significantly better than the John Deere 1450 CWS with efficiencies of 96.495 and 93.291% in high-density sites and low-density sites, respectively. Furthermore, due to the adjustment efficiency and engineering design of the New Holland TC56, harvest was completed in a shorter time.

Effect of the interaction between the planting density and the reel index on wheat harvest loss and harvester efficiency

The harvester level reel index 1.5 in high-density site had the lowest harvester losses of 2.977, 0.646, 1.419, 5.042, and 6.277% for header losses, threshing losses, separation, and cleaning losses, total harvest loss, total loss with higher harvester performance efficiency of 95.264%, as presented in Table 6. However, the highest total harvest loss of 13.938% was at a reel index of 2 in a low-density site. It indicates that the rotates of a reel with less advancement into the yield and increased tines hit the spikes harshly, resulting in increased losses; these observations agree with the results obtained by Bawatharani et al. (2013).

The results showed that the influence of planting density was different for each reel index. The dense field outperformed the less dense area with the lowest percentage of quantitative crop loss, especially in the cutting unit that caused more than two-thirds of the total harvest loss, where the values were (3.977, 2.977, 4.145) % (9.881, 7.601, 10.429) % for both fields with a reel index of 1,1.5 and 2, respectively.

Table 6. The impact of the interaction between the planting density and the level of reel index on percentage losses in wheat harvesting and efficiency of the harvester

Plant density	Reel index	*Percentage of header losses, %	*Percentage of threshing losses, %	*Percentage of Separation and cleaning losses, %	*Total harvest loss, %	*Total loss, %	**Harvester performance efficiency, %
High-density site	1	3.977 d	0.793b	1.722d	6.492 d	7.727d	93.955b
	1.5	2.977 e	0.646 c	1.419e	5.042 e	6.277 e	95.264a
	2	4.145 d	0.74 b	1.653d	6.538d	7.773d	93.897b
Low-density site	1	9.881 b	1.069a	2.46 b	13.41 b	14.977b	88.424d
	1.5	7.601 c	0.828b	1.909 c	10.337c	11.905c	90.885c
	2	10.429 a	0.815b	2.695a	13.938a	15.505a	87.892e

*The lowest values are the best; **The highest values are the best, the similar letters mean that there is no significant difference at the level of 5%.

Effect of the interaction between the reel index and the types of combine harvesters on wheat harvest loss and harvester efficiency

Wheat harvest loss and harvester efficiency were significantly affected by the combine harvester type and the reel index (Table 7). The harvest losses were significantly different ($P < 0.05$) between the levels of reel indexes in New Holland TC56 and John Deere 1450 CWS, while the losses at New Holland TC56 were significantly lower than that of John Deere 1450 CWS. In contrast, the total harvest loss was higher at level 1 of the reel index in John Deere 1450 CWS due to increasing both percentage of header losses and the percentage of threshing losses. The percentage of losses at level 1.5 of the reel index was lower than that of the reel index 1 and 2, the header losses were higher at level 1 of the reel index in John Deere 1450 CWS, while at the levels of reel indexes 1.5 and 2, there are no statistically significant differences concerning the percentage of threshing losses (Table 7). The harvester performance efficiency was significantly higher at the reel index of 1.5 and a significant difference between 1 and 2 reel indexes on New Holland TC56 and John Deere 1450 CWS. However, the harvester performance efficiency was higher at all the three levels of reel index in New Holland TC56 than that of John Deere 1450 CWS combine harvesters.

Table 7. The impact of the interaction between the types of combine harvesters and the reel index on percentage losses in wheat harvesting and efficiency of the harvester

Types of combine harvesters	Reel index	*Percentage of header losses, %	*Percentage of threshing losses, %	*Percentage of Separation and cleaning losses, %	*Total harvest loss, %	*Total loss, %	**Harvester performance efficiency, %
New Holland TC56	1	3.972 f	0.45 c	1.339d	5.76 e	7.03e	94.582b
	1.5	2.219 g	0.329 d	0.882 f	3.43 f	4.701f	96.696a
	2	5.594 e	0.468 c	1.067e	7.129 d	8.4 d	93.401c
John Deere 1450 CWS	1	9.886 a	1.412 a	2.843b	14.142a	15.674a	87.797f
	1.5	8.359 c	1.144 b	2.446c	11.949c	13.481c	89.453d
	2	8.979 b	1.087b	3.28 a	13.347b	14.878b	88.388e

*The lowest values are the best; **The highest values are the best, the similar letters mean that there is no significant difference at the level of 5%.

These results indicate that at the reel index of 1.5 in both combine harvesters, grain loss was statistically significant ($P < 0.05$) at a minimum compared to the other two levels of the reel index. Thus, the influence of the reel index and harvesters type on losses has significantly influenced.

Effect of the interaction between the planting density, types of combine harvesters, and the reel index on wheat harvest loss and harvester efficiency

Table 8 shows the influence of planting density, types of combine harvesters, and the reel index on the harvest losses and harvester efficiency. The results indicated that losses were influenced by the combine harvester type and the reel index in both Plant density sites. The header losses differed significantly ($P < 0.05$) between the reel index levels in New Holland TC56 and the high-density area. The losses at the reel index of 1.5 were considerably lower than that of 1 and 2. Otherwise, the header losses were not significantly at the three levels of reel index in John Deere 1450 CWS and high-density site. The wheat harvest losses at New Holland TC56 were considerably lower than John Deere 1450 CWS in high-density and low-density sites. The header losses, threshing losses, total harvest loss, and total loss were significantly higher at the reel index of 1 in John Deere 1450 CWS in low-density sites. In contrast, the separation and cleaning losses were considerably higher at the reel index of 2 in John Deere 1450 CWS in a low-density area (Table 8).

Table 8. The impact of the interaction between the planting density, types of combine harvesters, and the reel index on percentage losses in wheat harvesting and efficiency of the harvester

Plant density	Types of combine harvesters	Reel index	*Percentage of header losses, %	*Percentage of threshing losses, %	*Percentage of Separation and cleaning losses, %	*Total harvest loss, %	*Total loss, %	**Harvester performance efficiency, %
High-density site	New Holland TC56	1	2.639g	0.289 gf	1.101i	4.029g	5.177h	96.127b
		1.5	1.336 h	0.222 g	0.77k	2.328h	3.476i	97.725a
		2	3.595 f	0.308 fe	0.666 l	4.569g	5.716ih	95.631b
	John Deere 1450 CWS	1	5.315 e	1.297 b	2.342e	8.954e	10.277e	91.782d
		1.5	4.619 e	1.069 dc	2.069f	7.756f	9.078f	92.803c
		2	4.696 e	1.171 cb	2.639d	8.506e	9.829e	92.162d
Low-density site	New Holland TC56	1	5.305 e	0.61 e	1.576g	7.491f	8.885f	93.037c
		1.5	3.102gf	0.436 f	0.994j	4.532g	5.926g	95.666b
		2	7.594 d	0.627 e	1.468h	9.689d	11.083 d	91.17e
	John Deere 1450 CWS	1	14.458a	1.527 a	3.344b	19.329a	21.07a	83.811h
		1.5	12.1 c	1.219 cb	2.824c	16.142c	17.883c	86.103f
		2	13.263b	1.002 d	3.922a	18.187b	19.928b	84.614g

*The lowest values are the best; **The highest values are the best, the similar letters mean that there is no significant difference at the level of 5%.

The results showed statistically significant differences between the levels of reel indexes 1 and 2 in New Holland TC56 and John Deere 1450 CWS in both sites. The harvester performance was higher at reel index 1.5. However, the harvester performance was significantly higher at reel index 1.5 in New Holland TC56 and high-density site than that of all other interactions, and its highest performance efficiency reached

97.725%, as a result of achieving the lowest loss ratios in its units, especially the cutting unit and the total loss due to the high cutting efficiency. At the same time, the reel index 1 in John Deere 1450 CWS and low-density site recorded the lowest efficiency, which was 83.81%.

CONCLUSION

The current study aimed to investigate the effect of the New Holland TC56 and John Deere 1450 CWS combine harvesters based on a relationship between levels of reel index and plant density on a percentage of losses in harvest units, total harvest loss, total loss, and harvester performance efficiency. The data revealed that the best results were achieved with a 1.5-reel index level interacting with a high-density site; these results were statistically more significant than the differences between the New Holland TC56 and the John Deere 1450 CWS. It was observed that a reel index value of 1 or 2 results in a negative effect on all of the traits. In addition, the results showed positive superiority of the New Holland TC56 in the percentage of header, threshing, separation and cleaning losses, total harvest loss, and total loss with the highest performance efficiency of 97.725%; meanwhile, the John Deere 1450 CWS showed harvester performance efficiency of up to 92.80% and remained within the acceptable loss limits. A perfect setup of the combine harvesters is the most crucial prerequisite for reducing the number of harvest losses; therefore, it is recommended to expand the use of these modern harvesters by conducting more experiments and research in better conditions for wheat crops and combine harvesters.

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