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Optimization of Seed Corn Harvesting Losses Applying Response Surface Methodology

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Abstract: This study evaluated the amount of machinery losses during seed corn harvesting operation and investigated the relationship between cylinder and ground speed of the grain combine on total harvesting losses. For this purpose data were collected from a representative seed corn field which harvested using the grain combine. All types of losses measured based on a standard method and gathered as total combine loss. Response surface methodology based on two variables (cylinder and ground speed), three levels and Central Composite Design (CCD) was applied to find the optimum level of harvesting loss. Different models (linear, 2FI, quadratic and cubic), were tested and the 2FI model was selected as the best model which describes the relationship between dependent and independent variables. The predicted values were compared with the actual values of total losses and it was evident that the actual values were distributed relatively near to the predicted line which indicated that there is a good correlation between the actual and predicted values (with R^2 value of 0.88). The optimal condition in which the total combine harvesting losses was found the least at cylinder speed of 400 rpm and ground speed of 3 km/h.

Keywords: Central composite design, grain combine, response surface methodology, seed corn combine losses

INTRODUCTION

World population growth and the need for more food, led to the increasing of agricultural production at the global level. Approximately half of the population in the third world especially (developing country) in south west and south Asia does not have access to adequate food supplies (Anonymous, 2010). There are many reasons for this problem. One of the most important reasons which can be controlled easily is the crop loss which is occurring in the harvest and post-harvest operations. Harvesting losses cannot be completely eliminated, but they can be reduced to an acceptable amount. Corn has been, for many years, an important cereal crop in the world and nowadays with production of 818 million tones has taken the first rank in world production (Anonymous, 2008). United States of America with production of 333 million tones was in the first rank in 2009 and followed by China, Brazil, Mexico with amount of 164, 51 and 20 million tons (Anonymous, 2008). In this year Iranian corn production was approximately 1.6 million tons with average yield of 7.3 tons ha (Anonymous, 2008, 2009). Beside corn, seed corn is an important crop which is harvested for using in next corn cultivation season and should be out of any crack or damage. Iranian agricultural statistic data revealed the annual production of 15,500 tons in 2009 for seed corn with the average yield of 2.28 t/ha. Ardabil was the most important province in seed corn production and followed by Fars and Korasan-Razavi provinces (Anonymous, 2009). In order to produce a healthy and strong corn plant it needs to prepare seeds without any crack and break. For this reason seed corn harvesting operation should be done precisely. Every kilogram of seed corn (or any other crop) that is saved by careful use of harvesting machine, adds to profit a hectare (Hanna and Fossen, 1990). 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. 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 seed quality and minimize field losses.

Response Surface Methodology (RSM) is an one of the best known and effective statistical technique for optimizing complex processes because it allows more efficient and easier arrangement and interpretation of experiments compared to other methods (Box and

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Behnken, 1960; Gan *et al*., 2010; Gan and Latiff, 2011). The RSM, firstly induced by Box and Wilson (1951), is a method for creating a relatively accurate prediction of engineered system input-output relationships and optimizing the system being designed. RSM can not only express the relationship between input variables and output responses, but also achieve optimal bonding conditions through numerical optimization (Liu *et al*., 2012). The RSM have been applied successfully in numerous fields for optimization design (Acherjee *et al*., 2009; Choorit *et al*., 2008; Naceur *et al*., 2007) applied factorial design of experiments and response surface methodology to optimize bio-diesel production and found a second order model to predict conversions as a function of temperature and catalyst concentration (Vicente *et al*., 1998). Lee *et al*. (2006) used RSM for the determination of optimum extraction temperature and time to produce an acceptable banana juice extract and found temperature as the most important factor which affected characteristics of the banana juice extract (Lee *et al*., 2006).

After a long search there was no related study to the current research which used the RSM for modeling the combine harvesting losses but there were some studies on harvesting losses. 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, respectively) 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) (Zhang *et al*., 2009). 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 with cylinder speed of 550 rpm (Morvaridi *et al*., 2008). Quick (2003) established a hyperbolic relationship between grain damage and harvested yield for corn combines. He found a certain "sweet spot” in which the harvested or bin yield was optimal under the given crop conditions (Quick, 2003).

Based on the results of specified researches and the experimental observations it was concluded that travel (ground) and cylinder speed are the most important factors in seed corn combine harvesting which have a effective impact on the amount of losses. Therefore, the objectives of the present study were

- To study the effect of travel speed, cylinder speed on total combine losses
- To find the relationship between specified factors and total combine loss
- To find out the optimum conditions for cylinder and travel speed in which total combine loss is the least.

MATERIALS AND METHODS

Experimental design: In order to determine the total seed corn harvesting losses, a grain combine (four row CLAAS combine harvester) was applied. The experiment was conducted in Seed and Plant Improvement Research Institute (SPIRI) which is located in Alborz province of Iran in 2010. The cultivated seed corn variety in experiment plots was Single Cross 704, with row distance of 75 cm. The cylinder speed treatment was with three levels of 400, 500 and 600 rpm and 3, 4 and 5 km/h levels of ground speed treatment, respectively. In order to measure the combine cylinder speed, Tacho Hi tester (HIOKI 13404) was applied with five replications and to find the combine’s ground speed, a typical chronometer (stop watch) was used to determine the time passed in a 30 m combine’s run. The values of five replications of measured ground speed were averaged. All treatments were allocated to the plots where each plot consists of 30 m length and 3 m width.

Determination of losses: In order to calculate the total combine losses of seed corn harvesting, some standard techniques which are reported by other researchers (Hanna and Fossen, 1990; Huitink, 2008) were applied. Total combine losses are classified into two categories:

- Gathering losses are the seed corn ears and kernels which are missed by combine head in front of combine. This kind of loss was determined by applying a wooden quadrangular frame with area of 0.25 m^2. All ears and kernels which were fallen into this frame collected and weighed. Frames should cover the combine row width.
- Processing loss (threshing and separating losses) is found on the ground behind the combine and in combine’s tank. Threshing losses are kernels attached to pieces of cobs which are not being shelled by the combine cylinder and damaged kernels in tank. Separating losses are kernels that were not shaken out of the cobs and husks and were lost over the back of the combine. In order to calculate this kind of losses a closed bottom wooden rectangle frame (0.5×0.8 m^2) was used over the back of combine. In every experimental unit, three kernel samples were taken from combine’s tank to find the amount of broken and damaged kernels (which known as loss). 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.

Finally, by gathering all sources of total combine losses and dividing by seed corn yield the percentage of each harvesting unit losses were calculated.

Table 1: Independent variable levels

Independent variable (unit)	Symbol		Levels		
	Uncodified	Codified	-1	0	1
Cylinder speed (rpm)	X_1	x_1	400	500	600
Travel speed (km/h)	X_2	x_2	3	4	5

Statistical analysis: Response surface methodology is a collection of mathematical and statistical techniques, which consists of the experimental design for defining the range of the independent input variables, empirical mathematical model to explore an appropriate approximating relationship between the output responses and the input variables and optimization methods for achieving the optimum values of the process parameters that produce the desirable responses (Liu *et al*., 2012; Montgomery, 2001).

A central composite experiment design (Afoakwa and Yenyi, 2006; Quanhong and Caili, 2005) was set up using the Design Expert 8.0.7 software to study the response pattern and to determine the optimum combination of variables. The effect of independent variables of cylinder speed (X_1), ground speed (X_2) at three variation levels (Table 1) on the dependent variable (percentage of total losses) was evaluated.

The two independent variables were coded according to the following equation (Quanhong and Caili, 2005; Chen *et al*., 2011):

$$x_i = \frac{\left(X_i - X\right)}{\Delta X_i} i = 1,\ 2,\ 3 \qquad (1)$$

where, 'x_i' and 'X_i' are the dimensionless and the actual values of the independent variable 'i', 'X' the actual value of the independent variable 'i' at the central point and 'ΔX_i' the step change of 'X_i' corresponding to a unit variation of the dimension less value.

Experiments were randomized in order to minimize the effects of unexplained variability in the observed responses due to extraneous factors (Koocheki *et al*., 2009). As shown in Table 2, the total numbers of runs were 27 and the all of replicates of factorial points, replicates of star points and centre points were 3 for the method.

Experimental data were fitted to polynomial model to find the best model. The generalized second order polynomial model used in the response surface analysis was as follows (Wang *et al*., 2007):

$$Y = \beta_0 + \sum_{i=1}^{2} \beta_i X_i + \sum_{i=1}^{2} \beta_{ii} X_i^2 + \sum \sum_{i<j=1}^{2} \beta_{ij} X_i X_j \qquad (2)$$

where 'β_0', 'β_i', 'β_{ii}' and 'β_{ij}' are the regression coefficients for intercept, linear, quadratic and interaction terms, respectively and 'X_i' and 'X_j' are the independent variables.

In order to test the adequacy of the developed mathematical models and to indicate whether the model developed is meaningful the analysis of variance (ANOVA) methods were used. The ANOVA table for the model concludes the analysis of a response and the significant model terms (Liu *et al*., 2012). The significance test of regression model and lack of fit test are carried out by software Design Expert 8.0.7. The lack of fit value of the mathematical model implies that it is not significant. The other adequacy measures such as R^2 illustrates adequacy of the model.

RESULTS AND DISCUSSION

The Effects of the cylinder speed (X_1) and ground speed (X_2) on total losses were evaluated during experimentation. Data which are shown in Table 2 were tested with 27 runs in order to find the best relationship between independent and dependent variables. The maximum value of total losses was seen under the experimental conditions of X_1 = 600 and X_2 = 5 and the minimum percentage of total losses was under the experimental conditions of X_1 = 400 and X_2 = 3.

Fitting the model: The analysis of variance was performed for different model in order to find the best model with the highest significant. The significance of each model was evaluated by using the F-test and p-value.

As it can be seen from Table 3 the "linear" and "2FI" model were significant while the "2FI" model was the highest order model with significant terms. The results indicated that the "quadratic" model was not significant and the "cubic" model was found to be aliased.

The results of lack-of-fit sum of squares are shown in Table 4. The lack-of-fit test was done in order to find the model adequacy. This test is used in the numerator in 'F-test' of the null hypothesis and indicates that a proposed model fits well or not. The test for lack-of-fit compares the variation around the model with pure variation within replicated observations. This test measures the adequacy of the response surface model (Lee *et al*., 2006; Anonymous, 2011). The results revealed that there is significant lack of fit for all models. Significant lack of fit is not good and can be due to the kind of experiment but based on other model lack to fit result the "2FI" model was selected. Based on the results of Table 3 and 4 it became evident that 2FI model describes the relationship between independent (cylinder and ground speed) and dependent variable (total combine loss) well.

Table 2: Central composite design arrangement and results

		Independent variable (unit)		Dependent variabale (unit)	
Run	Experiment No.	Cylinder speed (rpm)	Travel speed (km/h)	Total combine loss (kg/ha)	Total combine loss(%)
1	21	400	4	398	8.2
2	22	500	5	441	9.1
3	8	600	5	436	9.0
4	14	600	3	388	8.0
5	24	400	4	412	8.5
6	7	600	4	429	8.9
7	4	500	3	397	8.2
8	23	500	5	450	9.3
9	25	500	4	411	8.5
10	10	400	3	405	8.4
11	13	600	5	449	9.3
12	6	600	3	393	8.1
13	16	400	5	401	8.3
14	5	600	4	431	8.9
15	18	400	4	406	8.4
16	15	400	5	400	8.3
17	11	500	3	402	8.3
18	9	600	3	387	8.0
19	20	500	5	439	9.1
20	26	400	5	413	8.6
21	2	500	3	392	8.1
22	19	600	5	433	9.0
23	3	500	4	412	8.5
24	12	400	3	395	8.2
25	27	500	4	407	8.4
26	1	600	4	436	9.0
27	17	400	3	393	8.1

Table 3: Analysis of variance for different models

Source	df	SS	MS	f-value	p-value	
Mean	1	4.61×10^{06}	4609494			
Linear	2	6.74×10^{03}	3371.694	24.12169	<0.0001	
2FI	1	1.39×10^{03}	1386.75	16.20747	0.0005	Suggested
Quadratic	2	2.65×10^{02}	132.4907	1.633812	0.2190	
Cubic	2	5.00×10^{02}	250.1389	3.95172	0.0367	Aliased
Residual	19	1.20×10^{03}	63.29873			
Total	27	4.62×10^{06}	171096			

Table 4: Lack of fit tests for different models

Source	df	SS	MS	f-value	p-value
Linear	6	2744.685	457.4475	13.49845	<0.0001
2FI	5	1357.935	271.587	8.014044	0.0004
Quadratic	3	1092.954	364.3179	10.75036	0.0003
Cubic	1	592.675959	2.6759	17.4888	0.0006
Pure error	18	610	33.88889		

Table 5: Analysis of variance for 2FI model

Source	Coefficient	Standarderror	df	SS	MS	f-value	p-value
Model	413.18	1.78	3	8130.14	2710.05	31.67	<0.0001
X_1	8.83	2.18	1	1404.5	1404.5	16.41	0.0005
X_2	17.22	2.18	1	5338.89	5338.89	62.40	<0.0001
$X_1 X_2$	10.75	2.67	1	1386.75	1386.75	16.21	0.0005
Residual			23	1967.93	85.56		
Lack of fit			5	1357.93	271.59	8.01	0.0004
Pure error			18	610	33.89		
Total			26	10098.07			

The independent variables were fitted to the recommended 2FI model and examined for the goodness of fit. Analysis of variance (ANOVA) for the suggested model is given in Table 5. As it can be seen, the model's "F-value" was 31.67 which implies that the model is significant. The value of "p-value probability" less that

0.01 indicates that the model terms are significant. The "F-values" of independent variable (X_1, X_2 and X_1X_2) which are shown in Table 5 revealed that all variables are significant ($p<0.01$). Based on the results of Table 5 it became evident that the change of cylinder speed and ground speed had highly significant effects on the total harvesting losses ($p<0.01$). The pure error for the model was 610 which it was similar to the other research results (Chen *et al*., 2011; King and Zall, 1992; Ye and Jiang, 2011). The high value for pure error was due to the kind of experiment. Because this study was a field experiment, there was more deviation between data in comparison with specified studies which were laboratory experiment.

In order to examine the goodness and evaluate the adequacy of fitted model several indicators were used that the results are shown in Table 5. The coefficient of determination (R^2), the adjusted determination coefficient (adj. R^2), coefficients of variation (C.V.%) were calculated to judge the adequacy of the model (Chen *et al*., 2011; Lee *et al*., 2006; Wang *et al*., 2007). The results indicated the values of 0.88, 0.84 and 2.22, respectively for coefficient of determination (R^2), the adjusted determination coefficient (adj. R^2) and coefficients of variation (C.V. %), respectively. The R^2 value of 0.88 indicates that 88% of the variability in the dependent variable could be explained by the model and 12% of the total variations cannot be explained by the fitted model (Chen *et al*., 2011). The R^2 value close to 1 shows that the predicted values from the fitted model are near to the actual data. The adjusted determination coefficient (adj. R^2) of 0.84 illustrated that there are excellent correlations between the independent variables.

Based on the results of Table 5 it was concluded that the linear term (X_1 and X_2) and interaction term (X_1 X_2) were significant while the Quadratic term (X_1^2 and X_2^2) was insignificant. Whit repect to Table 5 and the coefficints, the final equation in term of codded and actual factors are shown in Eq. (3), (4):

$$Y = 143.19 + 8.83\, X_1 + 17.22\, X_2 + 10.75\, X_1\, X_2 \qquad (3)$$

where "X_1" and "X_2" are the coded indipendent variable of cylinder speed and ground speed and "Y" is the total losse of seed corn during harvesting operation:

$$TL = 515.12963 - 0.34167\, CS - 36.52778 GS + 0.10750\, CS * GS \qquad (4)$$

where, "CS" and "GS" are the actual indipendent variable of cylinder speed and ground speed and "TL" is the total combine loss of seed corn during harvesting operation.

Analysis of response surface: The results of predicted and the actual values of total losses are shown in Fig. 1. The predicted values are obtained from the linear model Eq. (4) which had the best results of regression analysis. The predicted values are obtained from the linear model Eq. (4) which had the best results of regression analysis. As it can be seen the actual values were distributed relatively near to the predicted line and there is a good correlation between the actual and predicted values.

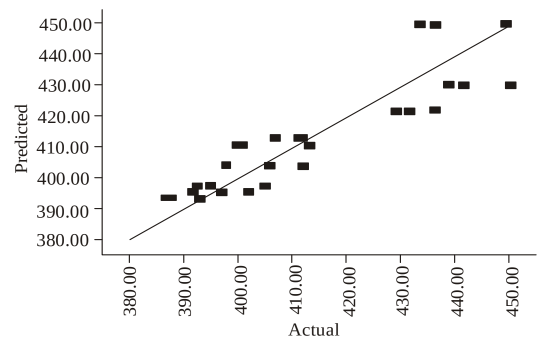

Fig. 1: Linear correlation between predicted and actual values

The relationship between independent and dependent variables is illustrated in tri-dimensional representation of the response surfaces and two-dimensional contour plots (Fig. 2). As it can be seen total harvesting losses increasses with an increase in grain combine cylinder and ground speed. The highest amount of losses occurred in cylinder and ground speed of 600 rpm and 5 km/h, respectively. Increasing the ground speed leads to more ears in gathering unit which is more than the working capacity of this unit. Excessive ground speed causes stalks to be crump and leads the ears to fall off the stalks ahead of the gatherer chains and out of the gathering unit (Hathaway, 1984). Applying higher values of ground and cylinder speed means more amount of entering corn ears and more stroke (from cylinder of threshing unit), respectively which increases the amount of losses in threshing and seperating units. More ground speed would increase the amount of feed rate which affects the quality of threshing unit efficiency and increase the amount of kernels attached to pieces of cobs which have not been shelled by the combine cylinder. On the other hand, higher level of cylinder speed raise the strokes and beats and accordingly the amount of broken seeds (Metianu *et al*., 1990; Morvaridi *et al*., 2008; SheikhDavoodi and Houshyar, 2010). The most difference between this study and other studies was the kind of harvesting crop. As it was specified in previous, because the harvested corn will be used in next cultivations and because the seed corn is sensitive to existence of any crack and damage, the output should be out of any crack and break (any crack in seeds decrease the seed generation rate). In seperating unit the higher volumes of ground speed (subsequently feed rate) can increase the amount of seed losses due to the high amount of cobs and husks. Based on the results of response surface methodology (Fig. 2) it was conculded that minimum amount of total harvesting losses will be seen in cylinder and ground speed of 400 rpm and 3 km/h,

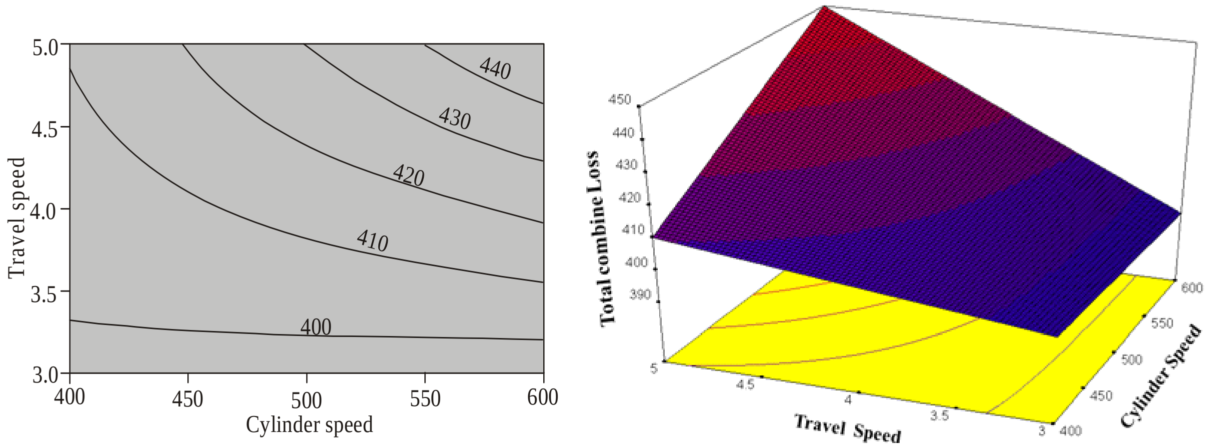

Fig. 2: Response surface and contours of cylinder speed vs. ground speed on amount of total combine losses

respectively which the amount of feed rate and cylinder strokes are least and all harvester units study in their highest efficincy.

CONCLUSION

The grain combine losses during seed corn harvesting operation were measured and the effect of different cylinder, ground speed on total combine loss was evaluated. The response surface methodology was applied to estimate and optimize the experimental variables. Different models were tested and the results indicated that "2FI" model displayed the relationship between parameters well. The results indicated that the change of independent variables had highly significant effects on the total combine loss. According to the selected equation, the optimum conditions for experimental parameters were obtained in which the cylinder and ground speed were 400 rpm and 3 km/h, respectively. The highest value of losses belonged to 600 rpm and 5 km/h.

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