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Application of Response Surface Methodology for Optimization of Picker-Husker Harvesting Losses in Corn Seed

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Abstract: Seed corn is one of the most important crops due to its high economical value. For this reason harvesting operation should be done precisely. Losses in harvesting seed corn are inevitable but can be decreased to the acceptable level. There are several machinery factors such as cylinder and travel speed which can affect total harvesting losses in two stage harvesting method (with picker-husker and sheller). For this purpose this study evaluated the amount of losses in different speed levels (3, 4 and 5 km h^{-1}) and cylinder speed (400, 500 and 600 rpm) and investigated the relationship between the specified factors (independent variables) and machinery losses (dependent variable). All types of machinery losses were measured and summed as total losses from a representative seed corn field. In order to find the relationship between the variables several models (linear, 2FI, quadratic and cubic) were tested. All analyses were done by applying the response surface methodology based on two variables, three levels and central composite design (CCD). Based on the results of this study, the relationship between cylinder and travel speed was analyzed and the corresponding model was designed. The results recommended that the 2FI model as the highest order model with significant term can describe the harvesting losses in relationship between cylinder and travel speed. The coefficient of determination (R^2), the adjusted determination coefficient (adjusted R^2) and coefficient of variation (CV) were calculated as 0.90, 0.89 and 3.69%, respectively and the response surface results showed that an increase of travel and cylinder speed would lead to an increase of harvesting losses. It was denoted that the travel speed have more impact on harvesting losses in comparison with cylinder speed. The optimization study showed the least harvesting losses of 209.88 kg ha^{-1} in cylinder and travel speed of 600 rpm and 3 km h^{-1}, respectively. It was concluded that the increase of travel and cylinder speed resulted in the increase of harvesting losses where the highest losses score was occurred in 5 km h^{-1} and 600 rpm, respectively.

Key words: Response Surface Methodology; Seed Corn; Picker-husker; Machinery Losses

INTRODUCTION

Corn has been, for many years, an important cereal crop that supply the world food need. More consideration to this crop leads to more increase of corn in comparison with other cereals such as wheat and rice. The global production of corn from 1960 to 1994 illustrated the production growth from 200 to 550 million tones [1]. The corn global production was 818 million tonnes in 2009. The cultivated area and yield were 158 million ha 5,161 kg ha^{-1}, respectively [2]. United States of America with production of 333 million tonnes

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was in the first rank in 2009 and followed by China, Brazil, Mexico with production amount of 164, 51 and 20 million tones [2]. In this year (2009) in Iran, the average yield of corn was 7.3 tonnes per hectare and the annual production was approximately 1.6 million tones [3].

The concerns about losses have been in existence since agriculture began. In recent years and due to the growth of world food demand, the importance of losses is more considerable. As much as half of all food grown is lost or wasted before and after it reaches the consumer [4, 5]. Cutting harvesting and postharvest losses can add a sizable quantity to the global food supply and leads to reducing the need to intensify production in the future. Due to high yield of corn, decreasing the amount of losses has become more importance. Minimizing corn harvest losses can mean substantially higher yields and profits.

The corn planting area had increased but there are many agro-technical issues to be solved, among them the question of seed corn harvesting. Based on Iranian agricultural statistic data the annual production of seed corn in 2009 was 15,500 tons with the average yield of 2.28 t ha^{-1}. Ardabil, Fars and Korasan-Razavi provinces were the most important producers of seed corn in Iran [3]. Seed corn is a crop which is used in next cultivation year and for this reason it is a sensitive crop which should be out of any crack or break. For years, corn mechanized harvesting was the ideal of farmers. The aim of mechanized harvesting operation is on time harvesting and threshing with least loss [6]. Two stage harvesting operation by applying picker-husker and sheller is a common method for seed corn harvesting. In this harvesting system, there are some factors that can reduce the losses (ground speed, header height of picker-husker and cylinder speed of sheller) [7]. During harvesting operation there are multiple independent variables affecting the other variables. In this situation it is essential to apply an optimization method which can show the main and interaction effect of all the factors on losses.

Response surface methodology (RSM) has been reported to be an effective tool for optimization of a process when the independent variables have a combined effect on the desired response. RSM is a collection of statistical and mathematical system that has been successfully used for developing, improving and optimizing in different systems [8-11].

Although several studies were done by applying RSM for optimization, there was no related research to the current study. In literature, Ayres *et al*. [12] measured visible in-field losses of 84 numbers of combines in north central Iowa. They found that a corn head row spacing difference of 5cm from the harvested rows resulted in an additional 82 $kgha^{-1}$ visible machine loss and that 65% of machine loss was at the corn head [12]. Hanna *et al*. [13] made a study on corn combine harvester and compared visible machine losses of a 76cm corn head used on 76cm and 38cm rows and a single gathering chain 38cm corn head used on 38-cm rows. The results illustrated on matched row spacing, machine losses were generally similar between the 76 and 38cm corn head and total machine loss of the conventional corn head (76cm) was significantly less than the single gathering chain corn head [13]. Morvaridi *et al*. [14] analyzed the effect of ground speed and cylinder speed of corn combine harvester [14]. Results indicated that the effect of ground speed on header loss and thresher loss 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. Quick (2003) found a hyperbolic relationship between grain damage and the amount of harvesting ears by corn combines. He found a optimum level of the factors in which the harvested yield is optimal under the given crop conditions [15]. In a study which was done by King *et al*. [16] the corn picker field tests showed that ground speed and snapping roll adjustment are the most important factors determining picking losses.

Based on the researchers' results, it is concluded that cylinder and travel speed are the most important factors in corn harvesters which can affect on amount of losses. So, the aim of the present study is to evaluate the effect of cylinder and ground speed on seed corn losses and to discover the relationship between two specified factors and total loss. Also, the optimum conditions for travel and cylinder speed in which total loss is the least, is another goal of this study.

MATERIALS AND METHODS

Experimental Design: There are two major harvesting systems in Iran for harvesting seed corn (one stage harvesting system by grain combine and two stage harvesting system by picker-husker and sheller). In this study the amount of harvesting losses of two stage harvesting system (two row picker-husker harvester (Tornado 80) and sheller) was evaluated and modeled. In order to determine losses, the experiment was conducted in Seed and Plant Improvement Research Institute (SPIRI) in Alborz Province of Iran in 2010 production year. The variety of harvested seed corn was single cross 704.

All treatments of cylinder speed (400, 500 and 600 rpm) and travel speed (3, 4 and 5 km h^{-1}) were allocated to the each experimental plots (every plot was 30 m long and 1.5 m width). In order to measure the picker-husker ground speed, a typical chronometer was used with five replications to determine the time passed in a 30 m picker's run and by recording the time, the speed was calculated easily. The cylinder speed of sheller was measured by Tacho Hi tester (HIOKI 13404) with five replications.

Determination of Harvesting Losses: Total machinery losses of two stage harvesting system of seed corn was calculated based on the standard techniques which are used by several researchers [17-19] with some changes. As it was specified in previous, seed corn is a crop harvested for using in next cultivation year and should be out of any crack and damage so harvesting of this crop should be done precisely. Harvesting losses (machinery losses) can be divided into two categories; gathering and processing:

1) Gathering losses which can be seen in front of picker-husker are the seed corn ears and kernels which are missed by picker head. In order to measure this type of losses a wooden quadrangular frame (0.25 m^2) was used. All ears and kernels which were not gathered by picker-husker head and were fallen into this frame were collected and weighed.
2) Processing losses which consist of threshing and separating losses which can be seen in sheller was determined in the second stage of seed corn harvesting. Threshing losses consist of two kinds of losses: (a) seed corn kernels which are attached to pieces of cobs and are not being threshed by the cylinder and (b) the broken and cracked kernels in tank of sheller. Separating losses are kernels that were not shaken out of the cobs and husks in sheller and were lost over the back of sheller.

In order to measure the amount of threshing and separating losses, all ears which were gathered by picker-husker (in different travel speed) were put in an elevator to feed the sheller and were shelled. For every experiment plots the amount of threshing and separating losses was calculated and weighed easily. In order to find the amount of broken and damaged kernels (which known as loss) three kernel samples were taken from sheller's tank in every experimental plot. The seeds were studied with a magnifier carefully to find any crack in them. Finally, the average weight for damage and broken seeds was calculated.

In order to calculate the feed rate Eq.(1) was applied:

$$FR = \frac{S \times W \times Y}{3.6 \times 10^4} \qquad (1)$$

Where, FR is feed rate (kg s^{-1}), S the travel speed (km h^{-1}), W the harvesting width (m) and Y the seed corn yield (kg ha^{-1}).

After measuring the amount of losses for gathering and separating harvesting units all values of losses were summed as total machinery losses.

Mathematical Models and Analysis: The statistical methodologies in different fields of research have been used for optimization [20, 21]. The conventional practice of varying one factor at a time, maintaining the other variables influencing the process at a constant level, does not, in fact, point out the combined effect of all the process variables and constitutes a time consuming methodology [22]. Beside conventional methods response surface methodology (RSM) is a collection of mathematical and statistical techniques that can be useful for modeling and analyzing situations in which a response of interest is influenced by several variables and the objective is to optimize this response [22]. Therefore, aim of RSM is exploring an appropriate approximating relationship between the output responses and the input variables and determination of the optimum operating conditions for a system under investigation or of a region of the factor space within which operating requirements are satisfied [23, 24].

A central composite design (CCD) with two independent variables (X_1, travel speed and X_2, cylinder speed) at three levels was performed by applying the Design Expert 8.0.7 software, in order to prepare data for statistical calculation, the variables were coded as [22];

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

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.

By using Eq.(1) the independent variables were coded and their levels are presented in Table1.

Table 1: Independent variable levels

Independent variable (unit)	Levels -1	0	+1
Travel speed (km h-1)	3	4	5
Cylinder speed (rpm)	400	500	600

Table 2: The treatment and central composite design arrangement.

		Independent variable (unit)		Dependent variabale (unit)	
Run	Experiment No.	Cylinder speed (rpm)	Travel speed (km h^{-1})	Machinery loss (kg ha^{-1})	Machinery loss (%)
5	1	5	400	230.6	6.29
2	2	3	400	201.2	5.49
23	3	4	600	253.2	6.91
26	4	4	500	251.3	6.85
20	5	4	400	232.4	6.34
19	6	4	400	229.3	6.25
4	7	5	400	246.4	6.72
18	8	5	500	269.4	7.35
10	9	5	600	274.6	7.49
24	10	4	600	245.3	6.69
14	11	3	500	199.7	5.45
11	12	5	600	291	7.94
3	13	3	400	215.6	5.88
1	14	3	400	213.7	5.83
21	15	4	400	226	6.16
6	16	5	400	233.5	6.37
25	17	4	500	224.6	6.13
16	18	5	500	263.4	7.18
7	19	3	600	206.5	5.63
12	20	5	600	284.1	7.75
27	21	4	500	247.4	6.75
8	22	3	600	208.5	5.69
13	23	3	500	227.6	6.21
15	24	3	500	204.5	5.58
22	25	4	600	244.5	6.67
17	26	5	500	247.4	6.75
9	27	3	600	211.1	5.76

Each independent variable had three levels which were coded as -1, 0 and +1. The experimental design was a central composite design (CCD) with three replications of a factorial point, stars points and center points in a total of 27 runs. Finally in order to minimize the effects of unexplained variability in the observed responses (due to extraneous factors) the experiments were randomized [8]. The treatments and the total harvesting losses are shown in Table 2.

In order to find the best model, different models were checked in which general model can be explained by Eq.(2) [25]:

$$Y = ß_0 + \sum_{i=1}^{K} ß_i X_i + \sum_{i=1}^{K} ß_{ii} X_1^2 + \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} ß_{ij} X_i X_j \qquad (3)$$

where 'Y' is the dependent response, 'β_0' is the constant coefficient, 'β_i' is the linear coefficient, 'β_{ii}' is the quadratic coefficients and 'β_{ij}' is the interaction coefficients, 'k' is the number of factors studied and optimized in the experiment, 'X_i', 'X_j' are the coded values of independent variables and the terms 'X_iX_j' and 'X_i^2' represent the interaction and quadratic terms, respectively.

ANOVA test was applied to evaluate the adequacy (by applying the lack-of-fit test) of different models and to evaluate the statistical significance of the factors in model. In order to examine the goodness and evaluate the adequacy of fitted model, coefficient of determination (R^2) was calculated. Design Expert 8.0.7 software was employed for the regression analysis and the graphical optimization, respectively.

RESULTS AND DISCUSSION

The results of 27 runs using CCD are given in Table 2. As it can be seen the amounts of total losses for each treatment of parameters were determined. The relationship between these parameters and total loss was studied. The results indicated that harvesting losses ranged from 5.45 to 7.94% of total yield with the average percentage of losses of 6.45%.

Table 3: Analysis of variance for different models

Source	DF	SS	MS	F-value
Mean	1	1508893.9	1508894	
Linear	2	13357.89	6678.94	46.272**
2FI	1	1718.41	1718.41	22.64**
Quadratic	2	126.04	63.02	0.817ns
Cubic	2	17.55	8.78	0.104ns
Residual	19	1602.143	84.32	
Total	27	1525716	56507.99	

ns: not significant **: significant at 1%

Table 4: Lack of fit tests for different models

Source	DF	SS	MS	F-value
Linear	6	1867.61	311.27	3.51*
2FI	5	149.19	29.84	0.34ns
Quadratic	3	23.15	7.72	0.09ns
Cubic	1	5.6	5.6	0.06ns
Pure Error	18	1596.54	88.69	

ns: not significant *: significant at 5% level

Table 5: Analysis of variance for 2FI model

Source	Coefficient	Standard error	DF	SS	MS	F-value
Model	236.4	1.68	3	15076.3	5025.43	66.21**
X_1 (Travel speed)	25.11	2.05	1	11350.2	11350.2	149.54**
X_2 (Cylinder speed)	10.56	2.05	1	2007.67	2007.67	26.45**
$X_1 X_2$	11.97	2.51	1	1718.41	1718.41	22.64**
Residual			23	1745.74	75.9	
Lack of Fit			5	149.19	29.84	0.34ns
Pure Error			18	1596.54	88.69	
Total			26	16822		
R^2	0.90					
adj. R^2	0.88					
CV	3.69%					

ns: not significant **: significant at 1%

Based on the results of Table 2 it became obvious that minimum losses occurred in cylinder and travel speed of 500 rpm and 3 km h^{-1}, respectively while the maximum percentage was shown in cylinder and travel speed of 600 rpm and 5 km h^{-1}, respectively.

Model Fitting: The F-value tests were performed using analysis of variance (ANOVA) to calculate the significance of each type of model. Based on the results of F-value the highest order model with significant terms which shows the relationship between parameters well and normally, would be chosen. As it is shown in Table 3, the quadratic and cubic models were not significant with F-values of 0.817 and 0.104, respectively while the other models (the linear and 2FI models) were significant ($p<0.01$) with F-values of 46.272 and 22.46, respectively. The results of Table 3 revealed that the 2FI model would be the recommended model because it was the highest order model with significant term in comparison with other models.

Besides evaluating the significance, the adequacy of the models was evaluated by applying the lack-of-fit test. This test is used in the numerator in an 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 measured the adequacy of the different models based on response surface analysis [26, 27]. As shown in Table 4 there was a significant difference ($p<0.05$) lack of fit for linear model however, the test was not significant for 2FI, quadratic and cubic models. The significant results of lack of fit for linear model showed that this model is not adequate. The results of Tables 3 and 4 indicated that 2FI model can describe the effect of cylinder and travel speed on total harvesting losses well. With respect to this result, the effect of each parameter was evaluated and shown in Table 5.

After denoting 2FI as the best model with the highest order, the independent variables were fitted in the specified model and the effect of each variable was evaluated. For this purpose and in order to appraise the adequacy of the fitted model several indicators were used. The coefficient of determination (R^2), the adjusted determination coefficient (adjusted R^2) and coefficient of variation (CV) were used to judge the adequacy of the model which these indicators were used by other researchers [25, 28]. The results indicated (Table 5) the model's F-value of 66.21 (significant in probability level of 99%). This significant level implied that there is only a 0.01% chance that model F-value this large could occur because of noise [25]. As it can be seen in Table 5 the F-value of independent variables (X_1, X_2 and X_1X_2) was 149.54, 26.45 and 22.64, respectively which implied that the effect of all parameters and interaction effect on dependent variable was significantly high. The F-value of 0.34 for lack-of-fit which it was not significant implied that the lack-of-fit for 2FI model was not significant. The coefficient of determination (R^2) and the adjusted determination coefficient (adj. R^2) were 0.90 and 0.89, respectively which illustrated that there are excellent correlations between the independent variables and the fitted model can describe the independent variables well [25]. The coefficient of variation (CV) which is independent of the unit is defined as the ratio of the standard deviation of estimate to the mean value of the observed response. This factor is a measure of reproducibility and repeatability of the models [25, 29]. The calculations indicated the CV value of 3.69% which illustrated that the model can be considered reasonably reproducible (because its CV was not greater than 10%) [25].

The second column of Table 5 is the coefficients of independent variables of 2FI model based on their coded variable. By means of these coefficints, the final equation which can show the relationship beween factors in term of codded is shown in Eqs.(3) as:

$$Y = 236.40+25.11X_1 + 1056X_2 + 11.97\, X_1X_2 \quad (4)$$

Where 'X_1' and 'X_2' are the coded independent variables of travel speed and cylinder speed and 'Y' is the total machiney losses of seed corn during harvesting operation.

By decoding the coded variable to the acual values Eq.(3) changed to Eq.(4) as:

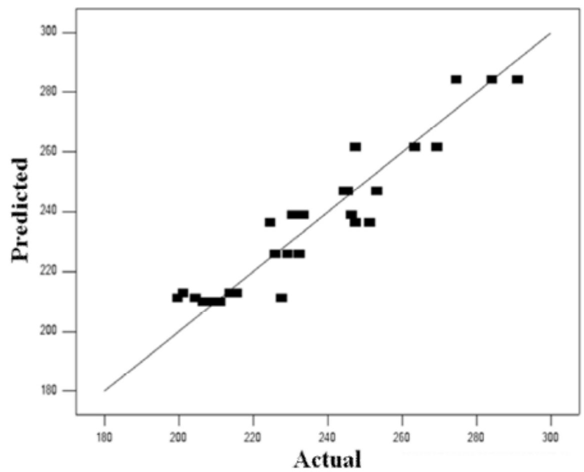

Fig. 1: Linear correlation between predicted and actual values

$$TL = 322.483 - 34.72\, TS - TS\text{-}0.37306\, CS + 0.1196\, TS * CS \quad (4)$$

Where 'TS' and 'CS' are the actual indipendent variable of travel speed and cylinder speed and 'TL' is the total loss of seed corn during harvesting operation.

After producing the final equations (Eq. (3) and (4)) the predicted values from the regression model were compared with the actual and experimental values. As it can be seen in Figure 1 the actual values were distributed relatively near to the predicted line and there is a good correlation between the actual and predicted values. This demonstrates that the fitted regression equation showed the fitting is good and the CCD model with an experimental design can be effectively applied for optimization [25].

Figure 2 shows the response surfaces and their corresponding contours of the combined effect of cylinder and travel speed on total losses. As it can be seen in Figue 2, increase of cylinder and travel speed led to increase of total losses. It is easily understandable from 3D graph that the highest harvesting losses occures in 600 rpm and 5 km h^{-1} of cylinder and travel speed. Increaing or decreasing the study factors effects on work of each harvesting unit and can change the amount of seed corn harveting losses. The cylinder speed have no effect on gathering unit and for this reason and because the harvesting was done in two stage, the effect of this factor was not evalated on losses of this unit. Increasing the ground speed leads to more ears in gathering unit which is more than the working capacity of this unit.

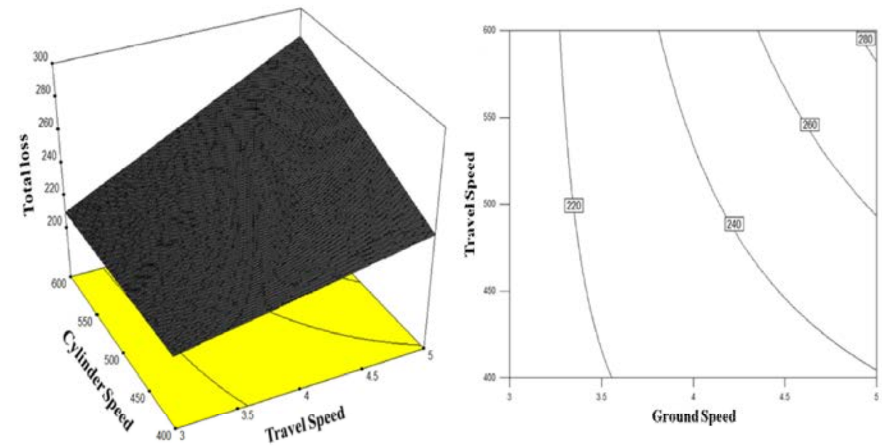

Fig. 2: Contours and response surface of cylinder speed vs. ground speed on amount of total losses

Table 6: Predicted and experimental values of the responses at optimum conditions.

		Total loss (kg ha)		Total loss (%)	
Travel speed (km h $^{-1}$)	Cylinder speed (rpm)	Predicted	Experimental	Predicted	Experimental
3	600	209.88	208.7	5.72	5.69

Excessive ground speed caused stalks to be crumped and led to the ears falling off the stalks ahead of the gatherer chains and out of the gathering unit [30]. In threshing unit higher values of travel speed signifies more feed rate and respectively more amount of entering corn ears. In this situation, threshing unit can not thresh all ears and the amount of kernels attached to pieces of cobs will increase. Moreover higher level of cylinder speed raise the strokes and beats and accordingly the amount of broken seeds [31]. The interaction effect of travel and cylinder speed is shown in Figure 2. One of the shares of total losses belongs to separating losses. 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. More cobs and husks effect on properly work of the seperation and will increase by increasing the travel speed.

The optimization study was performed to evaluate the optimal experimental parameters. Table 6 shows the optimum condition in which total harvesting losses is least. This optimal condition was in travel and cylinder speed of 3 km h $^{-1}$ and 600 rpm, respectively. As it can be seen the predicted of total loss was 209.88 kg ha $^{-1}$ while the experimental loss was 208.7 kg ha $^{-1}$. Also the percentage of the predicted and experimental of total losses was 5.72 and 5.69%, respectively. the results shows that there is small deviations between the experimental values and the predicted values and this results express that the CCD model can be used to optimize harvesting losses.

CONCLUSION

Based on the standard techniques the amount of seed corn harvesting losses by applying two stage harvesting methods (picker-husker and sheller) was measured (in different travel and cylinder speed). The response surface methodology was applied to find the best fitted model and the optimization level of study factor in which the amount of losses was the least.

The results showed that 2FI model was the highest order model with significant terms which showed the relationship well. The adequacy of the model was tested by lack to fit test and the results indicated that there was no significant lack to fit for 2FI model. The R^2, adj. R^2 and CV were calculated as 0.90, 0.89 and 3.69% that showed the excellent correlations between independent variables. The response surface results showed that increase of travel and cylinder speed led to increase of harvesting losses. Finally the highest harvesting losses observed in 3 km h $^{-1}$ and 600 rpm of travel and cylinder speed, respectively.

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