"Mathematical Modeling of Combine Harvester Header Loss using Dimensional Analysis"

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ABSTRACT

Wheat is a strategic crop which is considered to be one of the most important agricultural products. Harvest Loss is a type of loss that decreases final production performance. Combine harvester loss is divided to several losses; natural loss, header loss, threshing loss, separation loss and quality loss. The major loss is attributed to header loss. Combine harvester header loss is the consequence of cutter bar strokes, height of the reel, reel peripheral speed, travel speed, width of harvest, height of cutting, crop moisture, height and density of crop, feed rate of the crop and etc. Mathematical modeling of the combine harvester is the initial step to retrofit the performance of the combine harvester. Dimensional analysis is a method that uses effective variables and forms several dimensionless equations to evaluate the issue. The variables are changed to dimensionless equations and this reduces the number of variables. Accordingly, the numbers of required experiments to determine relationship between variables are decreased. This research has developed a model using combination of theoretical combination method (dimensional analysis) and practical phase (field experiments). This method uses most of the elements that have effect on loss. There were π-terms developed out of the effective elements, and the experiments were designed based on these pi-terms. Complete randomized block design was used in practical experiments. All the experiments were done in Pars-Abad with CLAAS combine harvester. Increasing travel speed in a defined range decreased header loss. Height of cut should be optimized because of some reciprocating reasons. The obtained data in analysis stage, verified the model with relatively high (76%) correlation coefficient.

Keywords: Mathematical Modeling, Combine Harvester, Header loss, Dimensional analysis, Iran

1. INTRODUCTION

12 million hectare of under cultivation fields are dedicated to annual agricultural products which 69.69%, 41.39%, 51.61% are allocated to cereals, irrigated wheat and dry land wheat, respectively. Cereal Combine harvester has significant role in harvesting industry because of the highly valued cereal products. One of the significant issues in this area is wheat loss from production to consumption and the solutions to

prevent and reduce it, especially in harvesting machineries. The significance of this topic is more crucial with the increasing wheat production. It is stated that these losses are up to 20% in some conditions (AMDF, 2001). Research studies reveal there are two main factors that cause header loss, i.e. the crops and the conditions of the machine which consist of natural loss, header loss, threshing loss, separation loss and quality loss. Investigations show that header has the most significant loss in cereal harvesting using combine harvester. Factors affecting the loss of this unit are as following: inappropriate cutting height, improper location of reel in relation to cutting bar, improper kinematic Index ratio and inappropriate velocity of cutting bar or broken blades (Mesri Gundoshmian et al., 2010). Cutting and feeding occur in header and the feeding space. These sections are maintained for cutting height, reel speed and height, and reel position. Cutting height is adjusted by the machine operator to harvest all the grains with the least straw and stubble.

The reel should be set in a way to be able to move the wheat stalks towards the cutting bar and to put them against it. Reel peripheral speed should be a little more than combine harvester travel speed and it should be placed in a right distance from cutting bar to lead the stems towards the platform. Cutting bar blades need to be sharp, dull blades limit the travel speed and end in grain loss because of vibration. Product feed rate has to be uniform during the harvest (Taylor et al., 1995). Grain loss caused by header vibration is the most significant wheat loss source without considering header type (Mcneil et al., 2009). All in all, header loss is in accordance with cutting bar strokes, reel height proportional to cutting bar, reel peripheral speed, travel speed, working width, cutting height, crop humidity, crop height and density, feed rate, etc.

In a study done in Fars (Rahimi et al., 2004) to determine wheat loss in harvesting stage, it was proved that the larger part of the loss (68% of total loss) was resulted by header. Kliner et al. (1972) investigated on combine harvester front loss for two different crops, wheat and oat. They plated the field and used a frame (1350 mm×100 mm) to measure the natural loss. They put these metal frames in the field covering the working width after the header of the combine harvester has passed the marked point. Natural loss mostly consists of grains and cutting bar loss was mostly ears.

Dimensional analysis identifies the effective variables and forms a complete collection of dimensionless equations in order to analyze the problem. It presents the phenomenon with a relation between several dimensionless equations which are less than number of variables. This method is used in different themes for prediction. Glancey et al. (1996) analyzed stripper combine harvester header loss for green peas. Loss in this combine harvester was due to crop and field properties, and header and combine design.

Using π-Buckingham theory and dimensional analysis the number of π-terms was reduced to six.

The results showed that the best combination of travel speed and reel peripheral speed are in 2.1 km per hour and 205 rpm, respectively. The header loss in this condition is 2.03 percent.

Degirmencioglu (1996) used dimensional analysis to predict a mathematical model for volume capacity and power estimation in grain conveyor system. Dimensional sets were made using π-Buckingham theory. Prediction equations were resulted from regression analysis. Lower speed, less steep, smaller spiral steps and larger entrance of the convey system were the factors to get close to higher performance.

2. MATERIALS AND METHODES

This study was accomplished in a field of Ardebil Agricultural Research and Education Organization (AREO) in Moghan. This field is located 10 km far from Pars-Abad. It has Mediterranean climate and the amount of rainfall was 486 mm in the year before this study. Harvesting machines used in this field were Claas Combine harvesters with conventional cereal header. Harvesting was done in 24-28 June, 2010. Tests were conducted in the format of randomized complete block. Travel speed (three levels), height of cut (three levels) and width of cut (two levels) were considered as the treatments, and each experiment was repeated three times. A wooden frame with the area of 0.25 cm^2 (50 cm×50 cm) was used to measure natural loss by collecting the grains and ears on the field inside the frame area. This was done in five replications and each replication was done in four different spots. The quantity of natural loss was calculated by averaging and extending to the field in terms of kg/ha. The percentage of natural loss is easily derived from this calculation and crop yield.
In order to measure combine harvester header loss, the same frame was located in between header and combine harvester front wheels after the machine has crossed that area. The grains and ears were collected and weighed. Natural loss minus this loss equals cutting bar loss (AMDF, 2001).
Natural loss and header loss measurements were implemented as the standard procedure mentioned in Khuzestan Agricultural and Education Organization.

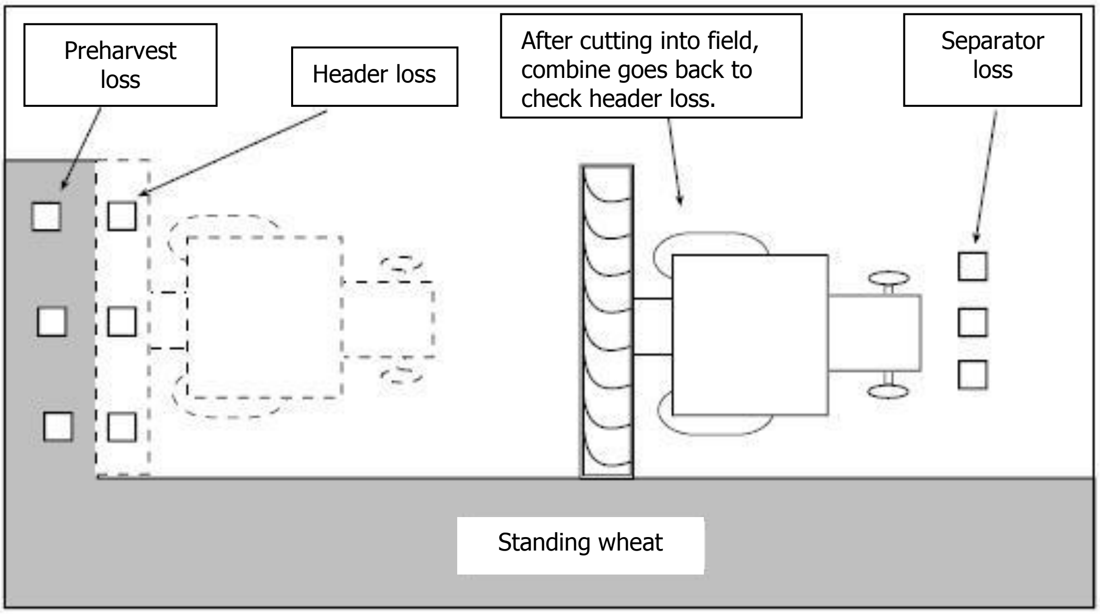

Figure 1. Measuring wheat harvest loss.

Samples of Natural loss, field yield and header loss were transmitted to grain technology laboratory in order to be count and weighed. The following equation was used to calculate the losses:

$$(kg/ha)NaturalLoss = 40000 \times g_n$$

$$(kg/ha)sideLoss = 40000 \times \frac{W_s}{w_{h_c}} \times g_s$$

$$(kg/ha)MiddleLoss = 40000 \times \frac{W_m}{w_{h_c}} \times g_m$$

$$(kg/ha)CenterLoss = 40000 \times \frac{W_c}{w_{h_c}} \times g_c$$

Where:

g_n = Average seed weight within each box of natural loss (kg),

g_s = Average seed weight within each box of side loss (kg),

g_m = Average seed weight within each box of middle loss (kg),

g_c = Average seed weight within each box of center loss (kg),

W_{h_c} = width of cut (m)

W_m = width of side of the header (m)

W_m = width of middle point of the header (m)

W_c = width of center of header (m)

The cutting height was determined by measuring the average remained stem in each frame in 5 spot. Crop density, linear density of crop stem and 1000-grain weight was also calculated.

3. RESULTS AND DISCUSSION

Dimensional analysis was done using thirteen variables:

$Loss$	Combine Header loss ،kg/ha
b	Working width ،m
d	Reel diameter ،m
h	Height of cut ،m
v	Travel speed ،m/s
u	Reel peripheral speed ،m/s

$\dot{x}$ Blades reciprocating speed .m/s

$\dot{m}$ Feed rate .kg/s

ρ Stem density .kg/m

N Number of wheat bush .1/m^2

W 1000-grain weight .kg

h' Vertical distance of reel from cutting bar .m

h'' Horizontal distance of reel from cutting bar .m

This method reduces number of variables and consequently the analysis is easier as the number of experiments required for determining the relation between variables is reduced. Dimensional analysis is used when variables of a phenomenon are known but the relation between them is not clear.

The data we have obtained from the experiments were substituted in equations and the results were analyzed. There were 10 π-terms obtained. We used π1 and π2 for the first analysis.

$$\pi_1 = {b.v.Loss}/{\dot{m}}$$

$$\pi_2 = {h}/{b}$$

And the relation between these two π-terms is:

$$\pi_1 = 2211\,\pi_2 + 66.52 \qquad R^2 = 0.87$$

The following equation is resulted from calculating the relation between π_1 and π_2, showing the relation between loss and other variables:

$$Loss = {[\dot{m}(2211\,{h}/{b} + 66.52)]}/{(b.v)}$$

This means that increasing combine harvester travel speed in a specific range, lead to header loss reduction. Glancey (1996) also showed that increasing the travel seed in range of 0.8-2.4 km/h decreases header loss. Mcneil et al. (2009) studied header loss and concluded that increasing travel speed up to 5 mile/h led to decrease in header loss.

Working width has reverse effect on loss meaning greater working width results in lower header loss. Cutting height should be considered from two different aspects. The stems are cut while reel bend the stems towards cutting bar. If they had to bend more, which happens in higher cutting heights, there would be more grain loss because of vibration. From another perspective, the stem gets thinner when we go up in the stem.

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.
The obtained data in analysis stage, verified the model with relatively high (76%) correlation coefficient.

4. REFERENCES

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