THE EFFECT OF SELECTED MECHANICAL
THRESHING PARAMETERS ON KERNEL DAMAGE
AND THRESHABILITY OF WHEAT

by

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INTRODUCTION

The Saskatchewan Agricultural Machinery Administration in its test work with combines, noted threshing difficulties particularly with the 1963 harvest. In one report from that year (17) the following was observed: "In many wheat crops, it was not possible to adjust the cylinder of the Cockshutt 431 so that the cylinder loss was acceptable, while keeping cracks and white caps at a reasonable level." In another report (MF 300) for the same year: "Best adjustment then gave 2 percent crackage with a cylinder loss of about 1 percent per head. Note that most of the cracks are lost over the shoe with the chaff." With regard to the last comment, it is necessary to point out that the test group assessed crackage on the basis of the quantity delivered to the hopper with the clean grain and did not consider the "cracks" lost over the shoe.

Investigations into the effects of mechanical threshing parameters on kernel damage and threshability of small grains appear in the literature as early as 1934, when Bainer and Borthwick (6) studied mechanical injury to seed beans. Since then, other studies (2, 3, 10, 14 and 15) have been carried out. These investigations indicate that cylinder speed is the primary influencing parameter while concave clearance, although of lesser significance, is an important factor as well. Because these studies were far removed from the climatic conditions of Western Canada, the possible varietal differences and the difficulties noted by Saskatchewan’s test group; a project with the following objectives was initiated.

1. Ascertain the importance of cylinder speed, concave clearance and feed rate with respect to kernel damage and threshability.

2. Determine if an optimum level of cylinder speed and concave clearance exists for minimum grain loss as suggested by Saskatchewan’s test group.

3. Explore the possibility that threshing is an impact and/or frictional process.

EQUIPMENT AND EXPERIMENTAL PROCEDURE

The stationary threshing unit used appears in Figure 1 and 2. The cylinder was a standard commercial rasp-bar type being 24 inches wide and 21 inches in diameter. It was used with the appropriate make of concave. The threshing unit was fed from a 50 foot canvas conveyer. The cylinder was driven by an IHC 706 diesel tractor. The conveyer and feeder chain were driven by a 3 hp electric motor, while the straw-walkers and the pan-under-walkers were driven by a 1/4 hp electric motor. The threshing unit lacked cleaning facilities such as sieves and fans, thus the total threshed sample (including grain, straw and chaff) was cleaned using a separate system. This system consisted of a series of three screens. The material first passed over a 3/8 by 7/8 inch expanded metal screen which removed straw as well as straw with unthreshed heads from the sample. A 14/64 inch round hole screen removed portions of the chaff and for final cleaning, a "Clipper" cleaner was used. The system was partially dictated by the necessity to avoid pneumatic separation until the last step in order to minimize losses of cracks and chips.

Figure 1. The stationary laboratory threshing unit used in this study.

Figure 2. The components of the laboratory threshing unit.
The threshing material used throughout the project was the hard red spring wheat variety, Park. The average grain-to-straw ratio was 1.00/1.71 and the average grain moisture content was 10.4% (wet basis). The wheat was taken from a field in the Leduc, Alberta area in sheaves and stored at the Ellerslie farm of the university until used.

The wheat sheaves were selected from storage at random and brought into the laboratory where they were placed on conditioning racks. The sheaves were left on the racks for five days before being used, in order to allow them to reach a moisture equilibrium. One hundred pounds of the conditioned material was weighed and placed on the 50 foot conveyor with the heads up and in line (8, 9). A combination of cylinder speed, concave clearance and feed rate was selected. Cylinder speed was considered at 5 levels: 800, 900, 1000, 1100 and 1200 rpm; concave clearance was considered at three levels: 1/4, 1/3 and 3/4 inch and feed rate was considered at three levels: 100, 200 and 300 lbs/min. This resulted in 45 different treatment combinations from which one was chosen using a random numbers table. The selected parameter values were set on the threshing unit and the material then run through. The catch was cleaned and weighed. The portion of the material containing unthreshed grain was run through the unit again to give the unthreshed portion. The rethresh material was cleaned and weighed.

Samples were taken from the original free grain catch using a sample divider. One hundred gram samples were used for grain moisture content determinations using whole kernel oven-dry methods (11). A 100 gram sample was taken for visual damage analysis (1, 4, 7).

ANALYSIS AND RESULTS

The data collected was analyzed on the basis of a randomized simple factorial experiment with four replications of all treatment combinations. Definitions of the dependent and independent variables (parameters) considered in this study were:

\[ Y_T = \text{Threshability} = \text{ratio of the wheat kernels (by weight) removed from the ear during initial treatment to the total expressed as a percent.} \]

\[ Y_D = \text{Kernel Damage} = \text{ratio of the wheat kernels (by weight), that show mechanical damage as determined by visual examination, including any broken, cracked or chipped kernels; to the total expressed as a percent.} \]

\[ X_S = \text{Cylinder Speed} = \text{speed of the cylinder measured in rpm.} \]

\[ X_C = \text{Concave Clearance} = \text{the distance between the cylinder beater bar and the front concave bar measured in inches.} \]

\[ X_F = \text{Feed Rate} = \text{the total material including grain, straw and chaff which passed through the threshing unit measured in lb/min.} \]

\[ X_SX_C, X_SX_F \text{ and } X_CX_F \text{ are the two factor interactions.} \]

Analysis of Variance

The results (Table 1) indicated that cylinder speed and concave clearance had a highly significant effect on threshability. The interaction of cylinder speed and concave clearance, which was also highly significant, indicated the differential response of threshability to cylinder speed depending on the concave clearance. Mean threshability in-

\[ \text{TABLE I. ANALYSIS OF VARIANCE (THRESHABILITY — } Y_T \text{)} \]

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degree of Freedom</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>S = Cylinder Speed</td>
<td>4</td>
<td>22.030</td>
<td>158.5**</td>
</tr>
<tr>
<td>C = Concave Clearance</td>
<td>2</td>
<td>11.570</td>
<td>83.2**</td>
</tr>
<tr>
<td>SC</td>
<td>8</td>
<td>1.270</td>
<td>9.1**</td>
</tr>
<tr>
<td>F = Feed Rate</td>
<td>2</td>
<td>0.012</td>
<td>&lt;1</td>
</tr>
<tr>
<td>SF</td>
<td>8</td>
<td>0.185</td>
<td>1.4</td>
</tr>
<tr>
<td>CF</td>
<td>4</td>
<td>0.085</td>
<td>&lt;1</td>
</tr>
<tr>
<td>SCF</td>
<td>16</td>
<td>0.038</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Error</td>
<td>135</td>
<td>0.139</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>179</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Significant at .05 level.
** Significant at .01 level.

1 Three decimal places were retained for calculation purposes only.

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increased with increasing cylinder speed (Figure 3), but decreased with increasing concave clearance (Figure 4).

Variations in mechanical damage between cylinder speeds, concave clearances and feed rates were statistically significant (Table II). The significance of the two factor interaction terms indicated that the factors did not act independently and that the influence of a factor on damage depended on the level of the other factors. Mean mechanical damage increased with increasing cylinder speeds (Figure 5), but decreased with increasing concave clearance (Figure 6) and increasing feed rate (Figure 7).

Multiple Regression
The general model considered for the multiple regression had the following form:

\[ Y = A_0 + A_1X_5 + A_2X_5^2 + A_3X_C + A_4X_F + A_5X_5X_C + A_6X_5X_F + A_7X_CX_F \]

\[ Y = \text{dependent variable (threshability or mechanical damage)} \]

\[ A_0 = \text{constant} \]

\[ A_1, A_2 \ldots A_7 = \text{multiple partial regression coefficients}. \]

A computer program for stepwise multiple regression (13) was used to determine the regression equations. All of the independent variables given in the general model were made available to the program, but only those which reduced the sum of squares by one percent or more were retained in the final multiple regression equations. The results of the regression analysis for threshability and mechanical damage are given in Table III and IV respectively.

The analysis of variance for the regression in both cases, indicated a highly significant reduction in sum of squares due to the regression. The multiple correlation coefficients of 0.91 and 0.98 indicated a good relationship between the dependent and the independent variables selected. The regression equations were considered to be valid within the range of values used in their determination. A necessary limitation of the equations would be that they are only valid when crop variables are similar to those used in this experiment, since moisture content, grain-to-straw ratio, and varietal differences are important crop parameters influencing threshability and kernel damage (3).
considered would result in an optimum situation of high threshability and low kernel damage, a measure of total grain loss was defined as follows:

\[ Y_L = (100 - Y_T) + Y_D \]

where \( Y_L \) = total grain loss (\%),
\( 100 - Y_T \) = unthreshed grain (\%) and
\( Y_D \) = damaged grain (\%).

The regression equation obtained for threshability is:

\[ Y_T = 87.9010000 + 0.021689X_S - 0.000010X_C^2 - 8.549019X_C + 0.006886X_SX_C \]

Multiple Correlation Coefficient = 0.91.

Cumulative Proportion of Sum of Squares Reduced = 0.82.

Standard Error of Estimate = 0.81%.

Thus, all unthreshed grain and damaged kernels were considered to contribute to grain loss in this definition. Small kernel fragments for example, are likely to be lost due to pneumatic separation (5) which is direct loss. Cracked kernels may result in dockage when wheat is sold for milling purposes and can be considered as a loss too. Damage may also result in poor germination if the grain is used for seed. Thus, any damage is undesirable and can be considered as a loss. Unthreshed heads which are retained for rethreshing often result in damaged kernels and can also be considered as a loss.

The regression equation for total loss \( (Y_L) \) in terms of the independent variables becomes:

\[ Y_L = 48.299000 - 0.103933X_S - 0.000064X_C^2 + 8.549019X_C - 0.011382X_SX_C \]

Multiple Correlation Coefficient = 0.95.

To determine the minimum of \( Y_L \), methods using partial derivatives (16) were used. The resulting solution indicated that minimum grain loss would occur at a cylinder speed of 751 rpm and .69 inch concave clearance. In this investigation the range of cylinder speeds was 800 to 1200 rpm. Since extrapolation of the regression equation beyond the values considered in the experiment is invalid, the solution is in question. However, the procedure is useful in that it indicates future experiments should consider lower cylinder speeds if minimization of grain loss is to be considered.

**DISCUSSION**

Threshability and Grain Damage

High cylinder speeds and small concave clearances resulted in increased threshability and increased mechanical damage (Figures 3, 4, 5 and 6). According to Arnold (3), an ear of grain is subject to large impulsive forces at high cylinder speeds. Decreasing concave clearance may have:

1. Increased the chance of an ear of grain being struck by the cylinder beater bar and,
2. Increased the chance of multiple impacts to the ear before it passed from the threshing zone.

It is convenient to describe the above as an "impact" process or model. Thus, the impact model may account for the increased threshability and kernel damage with increased cylinder speed and decreased concave clearance.

An increase in feed rate resulted in a decrease in mechanical damage (Figure 7). This might be due to a "cushioning" (5) effect at the higher feed rates. That is, the crop stream between the cylinder and concave may have been denser at the higher feed rates, thus providing a cushion for the kernels. The cushioning effect would fit the impact model. On the other hand, changes in the feed rate had no significant effect on threshability (Table I). The cushioning effect which may have decreased damage at the high feed rates, should also have decreased threshability. Since this was not supported by the results, a "frictional" model may be indicated. That is, increased feed rate may have increased the crop stream density which in turn increased the frictional forces between particles in the crop stream. Thus, the cushioning effect of the impact model may have tended to decrease threshability but was offset by the increased rubbing action of the frictional model. The net result could be little or no change in threshability.
The rubbing effect of the frictional model would not likely result in damaged kernels (12). In other words, the effects of cylinder speed, concave clearance and feed rate on threshability and kernel damage may be described on the basis of an “impact-friction” model.

Minimization of Grain Loss

As noted previously, the minimum total loss (Yₜ) would occur at cylinder speeds below 800 rpm (4396 ft./min). General recommendations (18) on settings of cylinder speed and concave clearance for combines indicate a cylinder speed of approximately 5300 ft./min and a concave clearance of % inch for the front and 1/8 inch for the rear. These recommendations were for threshing wheat under very dry conditions and were based on a summary of recommendations found in operator’s manuals published by combine manufacturers. In terms of this research, 5300 ft./min would indicate a cylinder speed of 980 rpm for the laboratory threshing unit. According to the findings of this research, the cylinder speed for an optimum situation of high threshability and low kernel damage would be below 800 rpm cylinder speed. This would imply that the general recommendations, as found in operator’s manuals for setting cylinder speed, are high.

It is believed that farmers adjust their combines according to the operator’s manual or by considering the threshability without due regard to mechanical kernel damage. If this is the case, they are probably using cylinder speeds which are unnecessarily high and the result could be excessive damaged kernels along with high threshability.

CONCLUSIONS

Conclusions that can be drawn within the limitations of crop variety and moisture content are as follows:

1. The mechanical parameters causing significant variation in threshability are cylinder speed and concave clearance.

2. The mechanical parameters causing significant variations in percentage mechanical damage are cylinder speed, concave clearance and feed rate.

3. Threshability can be expressed in terms of the mechanical parameters by a regression equation of the form:

   \[ Yₜ = A₀ + A₁X₅ + A₂X₅² + A₃X₇ + A₄X₇X₇ \]

   where \( Yₜ \) is percentage threshability, \( A₀ \) is a constant and \( A₁, A₂, A₃, A₄ \) are partial regression coefficients. \( X₅ \) and \( X₇ \) are the mechanical parameters of cylinder speed and concave clearance respectively.

4. Mechanical damage can be expressed in terms of the mechanical parameters by a regression equation of the form:

   \[ Yₒ = B₀ + B₁X₅ + B₂X₅² + B₃X₇X₇ \]

   where \( Yₒ \) is percentage mechanical damage, \( B₀ \) is a constant and \( B₁, B₂, B₃ \) are partial regression coefficients. \( X₅ \) and \( X₇ \) are the mechanical parameters of cylinder speed and concave clearance respectively.

5. A level of the variables (parameters) considered in this project that would result in an optimum situation of high threshability and low kernel damage was not obtained.

6. In practical situations, combine operators should consider kernel damage as well as threshability in adjusting their combines.

REFERENCES


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tactor, provide another current path and the contactor stays closed even thought the first microswitch has re-opened under grain pressure.

4. When the grain level rises to a certain height, grain will press against a second paddle forcing open another microswitch located in the AND circuit of the contactor.

5. a) The contactor releases and the elevator motor stops. When the grain level drops and pressure is released from the top paddle the microswitch recloses. However, the OR part of the circuit is now open so that the contactor remains open.

2. This is only necessary to prevent the elevator from running uselessly if the grain supply fails. Another pressure operated microswitch, held closed by the presence of grain, is located at the outlet of the main supply bin. The switch is connected into the AND circuit of the contactor. If the grain supply fails this switch opens and the contactor opens cutting off the elevator motor.

The unit can be shut down part way through a cycle by depressing the stop button which is located in the AND circuit: The contactor opens and the circuit remains off until the grain level drops below the bottom grain sensor. The addition of a hand-off-automatic switch instead of the start-stop buttons adds more sophistication to the circuit. This allows the unit to be manually (hand) operated, locked off (off) or run automatically. If desired, the three microswitches can be connected to operate indicator lights to show at a remote location the condition of the system.

This one method of automating this operation is arrived at by the substitution of control elements for human action.

There is another solution. This second solution uses a long tube of reasonable diameter (3 to 4 inches). At the bottom of the tube a pressure sensitive switch is located which is connected into the AND circuit of the contactor. Grain pressure holds this switch open. The tube is located so that when the bin is almost empty grain runs out of the tube releasing the pressure from the switch which then closes. The contactor closes and the elevator motor starts. When the bin is almost full grain overflows into the tube containing the pressure switch. Grain pressure opens the switch and the contactor opens. Another pressure switch located at the main grain supply outlet, connected into the contactor AND circuit will cut the unit off if the grain supply fails.

This second system does what is required, that is to automatically re-fill the bin. It is not, however, as versatile as the first nor as trouble free but, using fewer components, is cheaper. These two solutions show two approaches to the same problem.

REFERENCES

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ment of certain objectives in our chosen profession geared to the betterment of the agricultural industry. Results by themselves are of little use, however, unless made public. The philosophers have not included in their rules the necessity of publishing the results of tests, or of experimental and development projects. Here lies a most critical test of new theories and predictions.

17. Reed, W. B. and E. O. Nyborg. Cockshutt SP431 and Massey-Ferguson 300. Test Reports, Saskatchewan Agricultural Machinery Administration.