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NAME OF AUTHOR: LALMOHAN SAMANTARAYA

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(Signed) L. Samantaraya

PERMANENT ADDRESS:

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THRESHING LOSSES OF SPRING WHEAT (CULTIVAR PARK)

by

© LALMOHAN SAMANTARAYA

A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled "Threshing Losses of Spring Wheat (Cultivar Park)" submitted by Lalmohan Samantaraya in partial fulfilment of the requirements for the degree of Master of Science.

Supervisor

Date Nov. 19 / 1974

ABSTRACT

The effect of the combine cylinder speed, the feed rate of the crop, and the crop moisture content on the kernel damage and threshability was determined for the cultivar Park. The cylinder speeds were 700, 900, and 1100 rpm (4000, 5200 and 6300 ft/min) and the feed rates were 100, 150, and 200 lb/min. The moisture content of the grain was varied from 12 to 20% in increments of 2% and was achieved by exposing the crop to appropriate temperatures and humidities.

The project was a factorial experiment with four replications for all treatment combinations. The results indicated the following:

- as the cylinder speed was increased, the kernel damage and threshability were increased,
- as the moisture content was increased, the grain damage and threshability decreased except at the 18% moisture level,
- for minimum kernel damage and maximum threshability (minimum loss), the optimum cylinder speed was 1100 rpm or greater (6300 ft/min),
- except at the 12% moisture content, the kernel damage and threshability were independent of the feed rate,
- the grain loss due to the amount of kernel damage and grain left in the head was not independent of the moisture content.

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1. INTRODUCTION

Grain production is an important segment of the agricultural industry and, therefore, grain losses whether from insects, disease, or a combine is pertinent to the farmer, the food processor and the consumer. In spite of investigations into harvesting, the relationship between the mechanical factors of the combine and the biological factors of the cultivar is not well established. For example, it is impossible to advise a farmer what the cylinder speed of his combine should be for minimum grain loss given the moisture content of the cultivar.

According to Harrison (22) the capacity of a combine is specified by the grain loss and one source of this grain loss is the combine cylinder. Cylinder loss occurs because of grain that is left in the head which is subsequently expelled with the straw, and because of broken kernels which are subsequently expelled with the chaff. Retained damaged kernels may be a loss because of the possibility of mold development in storage ([illegible]). Grain for seed is easily damaged since even small cracks in the seed coat will allow bacteria to enter and prevent germination.

Objectives.

In the prairies of Western Canada a wide variety of crop conditions occur because they are located in the temperate zone far from the moderating influence of the ocean. In the early part of the harvest season, it is often hot and dry but the later part is cold and frequently wet and sometimes the harvest is terminated by snow. Because the best part of the harvesting season is short, the combine capacity is frequently exceeded causing excessive grain losses (35). In addition, farmers usually adjust the cylinder speed and concave clearance on the basis of not leaving any grain in the head; that is, they attempt to obtain maximum threshability without giving much consideration to the amount of grain they may be damaging (35). As noted previously, cracked kernels are expelled with the chaff by pneumatic separation and the operator is usually unaware of this loss. In other words, the benefit of increased threshability may be offset by an increase in grain damage with an immediate and often a subsequent loss.

In general, information gained concerning such effects as the cylinder speed of the combine and the moisture content of grain on the threshability and grain damage should be useful to combine operators and because of its pertinence to the agricultural industry is the objective of this investigation.

2. REVIEW OF LITERATURE

Grain Loss.

Vas and Harrison (36) have defined that the loss of grain associated with the cylinder of a combine is the sum of the damaged and unthreshed grain. The latter is readily determined by rethreshing, but the former is difficult and complicated because it is not readily defined. In fact Agness (1) has stated, "Defining corn kernel damage in terms acceptable to all segments of the corn industry is an impossible task." The author (1) discusses various methods for evaluating mechanical damage and subsequently used two procedures. Chung and Converse (16) stated that grain damage could be classified as external or internal. They added that both types of damage might also occur with either physical or physiological changes in the grain prior to harvesting and during storage and handling after harvest. They found that physical damage enhances certain physiological changes that accelerate the deterioration of the grain. They concluded that external damage occurs largely with threshing and transporting after threshing, whereas internal damage occurs in storage.

According to Mohsenin (26) kernel damage occurs when the kernel is forced through too small an opening or experiences too great an impact during threshing. The author alleges that damaged grain does not germinate well, has a greater tendency to develop mold when stored and adversely effects the milling quality if the species is wheat. Grain damaged by impact may vary from a complete splitting of the kernel into two or more segments to small hairline cracks invisible to the naked eye. Even small cracks in the kernel coat may allow soil bacteria to enter the kernel and inhibit viability.

It is evident that damaged kernels are a loss even when they are not expelled with the chaff from the combine and that grain damage is never less than that reported by any investigator. On the other hand, grain left in the head or threshability can be readily determined.

Cylinder Speed.

The most common cause of grain damage is the shock and impact experienced by the kernel during mechanical handling (15). Louvier and Calderwood (25) conducted a series of tests to find the amount of breakage which would result from dropping milled rice from various heights onto a bin floor. The amount of breakage increased with an increase in the velocity at the time of impact. Breakage was reduced 60% if the floor sloped 45^0 with respect to the horizontal. Impact is a function of the change in velocity which is reduced for an inclined surface.

Pickett (31) stated that in harvesting navy beans, damage increased as the cylinder speed increased. Clark et al (18), in an attempt to determine the effect of impact with cotton seed, concluded that "at energy absorption levels above three-inch ounces, slowly applied loads are more detrimental to seed germination than dynamic loads". They added that cotton seed is more susceptible to damage from impact on the side than on the radicle end of the kernel and that there is no direct relationship between damage and moisture content. Bilanski (13) studied the effect of impact and found that corn was weakest when placed on its edge and strongest when placed on its flat side.

Arnold and Jones (7) found that complete avoidance of breakage of Cappelle Desprez wheat with a moisture content of less than 15% was possible only with cylinder speeds less than 3600 feet per minute. They also found that Koga 2 wheat was more resistant to breakage than Cappelle Desprez indicating a cultivar difference with respect to damage. Arnold (4) stated that increasing the cylinder speed from 3500 to 6500 feet per minute reduced the amount of unthreshed grain but failed to achieve 100% threshing efficiency, the maximum being 99.5% for grain at a moisture content of 13.7%. Vas and Harrison (36) found that threshability (threshing efficiency) increased with an increasing cylinder speed but at a decreasing rate with little increase above 1000 rpm (5496 ft/min). Arnold (4) concluded that to achieve 100% threshability, that is, remove the last few kernels from the ear, a cylinder speed considerably greater than 6500 ft/min would be necessary.

King and Riddolls (24) found differences in damage of wheat and peas for different cylinder speeds to be highly significant in the range of 1000 to 1400 rpm. The damage increased approximately 1% for each 50 rpm increase. The damage ranged from 1.8 to 16%. In the next year they used cylinder speeds ranging from 600 to 1200 rpm in 100 rpm increments. Again the damage at different cylinder speeds was significant and increased by approximately 3 1/2% for each 100 rpm increase.

Cylinder diameter and bar spacing.

Arnold (4) found an optimum cylinder diameter (21 in.) with regard to kernel damage, but the effect was so small that it could be neglected. Arnold (4) and Arnold and Jones (7) found no evidence that the bar spacing effected the kernel damage. As for threshability, there is an apparent lack of references regarding the effects of cylinder diameter and bar spacing.

Concave clearance.

Arnold and Lake (5) concluded that for the cultivar Cappelle Desprez, a small concave clearance (3/4 in.) caused appreciable damage if the moisture content was low (< 15%). Though they found a relationship between concave clearance and damage, they noted that the clearance had no effect on germination. As for threshability, they obtained an increase in the amount of unthreshed grain if they increased the clearance from 1/4 in. to 5/8 in. For the cultivar Park, Vas and Harrison (36) determined that the difference in threshability between 1/2 in. and 3/4 in. concave clearance was greater than the difference between 1/2 in. and 1/4 in. concave clearance, especially at a low cylinder speed.

Concave length.

For the cultivar, Koga 2, Arnold and Lake (5) obtained less than 1% unthreshed grain (threshability) at all cylinder speeds over 3500 ft/min when a 20 in. concave length was used. Using a 6 2/3 in. length of concave, the unthreshed portion ranged from 5% at 3500 ft/min to 2% at 4500 ft/min. With regard to grain damage, a small increase, less than 0.4%, occurred if the concave length was doubled from 6 2/3 in. There was no additional damage for additional concave lengths.

These authors also found that a closed concave caused four times as many broken kernels as an open type. The concluded that the difference in threshability produced by the two concaves was negligible.

Feed rate.

Bunnelle et al (14), and others (10,21,29,30), state that increasing the throughput or feed rate increased the amount of unthreshed grain in the rack and shoe effluent (threshability). They frequently found that the relationship between the feed rate and the threshability was linear. On the other hand, Arnold (4) found that within a feed rate of 72 to 240 lbs/min, there was no apparent change in the threshability. Neither did Vas and Harrison (36) experience a threshability response for feed rate. Nyborg et al (30) found a decrease in the threshability for an increase in the grain to non-grain ratio, when the non-grain feed rate was held constant.

Arnold (4), Arnold and Lake (5) and Bainer et al (12) found that an increase in the feed rate reduced the damage although the effect was usually small. For example, the damage experienced by Arnold (4) fell within the range of 0.68 and 0.33%. Vas and Harrison (36) noted a similar decrease in damage for an equal increase in the feed rate.

Crop presentation.

Arnold (4) noted that the manner in which the crop was fed to the cylinder had no effect on the kernel damage or viability of either wheat or barley. On the other hand threshability was greatly improved when the crop was presented head-first as opposed to butt-first. For feeding wheat and barley butt-first, the cylinder loss (threshability) was more than twice as great as when the crop was fed to the cylinder head-first, head-on-top, and stalks parallel (normal).

Moisture content.

Arnold and Jones (7) and Arnold et al (8) allege that grain damage is consistently greater for low moisture grain than for high. They found that damage was minimum in the moisture range of 17.5% to 22% and concluded that this moisture content is a "safe zone" with regard to grain damage. Arnold et al (8) found that with an increase in the moisture content of wheat from 15 to 25%, the grain loss doubled indicating that threshability decreases with an increase in the moisture content.

Caldwell and Mitchell (17) determined the amount of grain damage for different moisture contents, concave clearance, and cylinder speeds. The greatest incident of grain damage occurred at the lowest moisture level, 16% moisture content, and at the highest cylinder speed. At all moisture levels the lowest cylinder speed was associated with the least amount of damage. They recorded grain damage up to 61% which may reflect their assessment criteria which specified that a kernel was considered damaged if it had any break in its surface when examined under a microscope.

King and Riddolls (24) extended their previous study and found that damage at a cylinder speed of 1200 to 1400 rpm was much lower for a moisture content of 19.2% than at 13.2%. The effects of moisture content and cylinder speed were both significant. Using a narrower moisture range in a subsequent year, they found that only the cylinder speed was significant.

Arnold and Jones (7) investigated damage caused by different cylinder speeds and moisture content. They selected combine harvesters at random and took grain samples from the machines at regular time intervals. They recorded the cylinder speed for each machine, and for each sample, determined the moisture content and the percentage of damaged grain. The moisture contents ranged from 16.1 to 31.8%, cylinder speeds from 4335 to 6447 ft/min. and grain damage from .7 to 10.6%. A regression analysis of the data indicated that the damage increased with cylinder speed and decreased with moisture content.

Goss et al (21) found that when harvesting barley at 7 to 9% moisture content in California, grain damage amounted to 5% at a cylinder speed of 3800 ft./min. For harvesting barley in Minnesota at 12% moisture content and a cylinder speed of 4800 ft./min., Delong and Schwantes (19) found the damage to be 1 1/3 times that found by Goss et al (21). Caldwell and Mitchell (17) found that the germination of wheat and oats was reduced when the crops were threshed at a grain moisture content other than in a range of 17 to 22% and this agrees with Arnold's concept (7) of a "safe zone" of moisture content. Other investigators (9, 12, 14, 19, 21) have indicated that grain damage increases with a decrease in the moisture content but there does not appear to be enough research to firmly establish the relationship between threshability and moisture content.

Summary.

Investigations by various researchers indicate that the speed of impact is the prime cause of kernel damage. In the first instance; impact is imparted to the kernel by the cylinder bar. The concave bars prevent some of the grain from moving outward, thus imparting another impact and causing a repeat of the sequence. The kernel will absorb some of the impact energy but if the velocities are too large, damage will occur. On the other hand, as the cylinder speed increases the threshability increases and at high cylinder speed there is less unthreshed grain. High feed rates cause less kernel damage and low threshability, though some authors found no change in threshability with a change in feed rate. Another factor is concave clearance. A decrease in clearance causes greater damage and higher threshability but the change is minor relative to the cylinder speed. The effect of cylinder diameter and concave length are also minor relative to cylinder speed. On the other hand kernel damage and threshability increase substantially with a decrease in the moisture content of the grain.

3. EXPERIMENTAL DESIGN

Selection of Variables.

The evidence from the literature review is that the variables or factors affecting grain damage are the cylinder speed, feed rate, concave clearance, cylinder diameter, cylinder bar space, concave length, moisture content, crop presentation and the cultivar. Of these factors, cylinder speed, feed rate, and concave clearance are easily changeable and are the usual adjustments available to the operator. With the exception of the concave clearance these factors were varied in the experiment. The concave clearance was not altered on the suggestion of Vas (35). Moisture was included in the experiment because of its importance with regard to grain damage and threshability. With regard to crop presentation, the normal mode of heads-first, heads-on-top was used. Cylinder diameter, bar spacing and concave length were not varied because of the limited response experienced by other researchers and the difficulty in effecting their change.

Variable Definitions.

Moisture content (XM) on a wet basis is the percent by weight of water removed from the grain when dried at 266^{0}F for 20 hours (20).

Cylinder speed (XS) is the rotational velocity of the cylinder in revolutions per minute.

Feed rate (XF) is the total amount of material including grain, straw and chaff that is fed to the cylinder per unit time expressed in pounds per minute.

Kernel damage (YD) is the percent weight of kernels in a sample that exhibits any damage as determined by visual examination including all broken, cracked or chipped kernels.

Initial threshed grain (W1) is the amount of grain collected during the first threshing of the crop that was not expelled with the effluent.

Rethreshed grain (W2) is the amount of grain collected from a second threshing of the crop. This grain was left in the head during the initial threshing and is normally lost or wasted.

Threshability (YT) is the percent by weight of grain removed from the head during initial threshing; that is,

$$YT = (W1/W1 + W2)\ 100$$

Total wastage (YTW) is the amount of grain damaged plus the amount of grain left in the head; that is,

$$YTW = (YD \times W1) + W2$$

Selection of Factor Levels.

Vas (35) found a minimum grain loss or wastage at a cylinder speed of 751 rpm and, therefore, 700 rpm was selected as the minimum speed for the experiment. Arnold (4) found that grain damage was a minimum within the range of cylinder speeds of 4500 to 5500 ft./min. A cylinder speed of 900 rpm was selected because it fell within this range. Because the highest cylinder speed suggested by the manufacturers for threshing wheat is 1140 rpm, a cylinder speed of 1100 rpm was selected as the maximum.

Five levels of moisture content were selected in anticipation of obtaining a curvilinear relationship between the dependent variables and the moisture content. In Western Canada, whenever possible, grain is harvested at a moisture content which will avoid the necessity for subsequent artificial drying. For wheat this moisture content is 14% and was, therefore, one of the levels selected. Because threshing occurs at moisture contents below 14%, a 12% level was included. In other parts of the world, such as the United Kingdom, threshing is carried out in a range of moisture contents between 17 to 22%. In view of this the other three levels of moisture content selected were 16, 18, and 20%. The higher moisture contents were included to explore the application of threshing at these levels in Western Canada.

It was intended to use the same levels of feed rate as Vas (35) but, with the higher moisture grain, there was insufficient power. In this circumstance the maximum feed rate was 200 lbs/min. The other two feed rates were 100 and 150 lbs/min.

Statistical Design of Experiment.

The experimental design is a split-plot (Table 1) and was selected rather than the complete randomized block because it was impractical to randomize the moisture content. A minimum of one week was required to obtain a desired moisture content and, therefore, it was necessary to condition all the grain required for a replicate at one time. The split-plot design provides some estimates with greater precision than others (32,38).

TABLE 1: FORM OF ANALYSIS

SOURCE OF VARIANCE	DEGREE OF FREEDOM
Replicate (R)	3
Moisture Content (M)	4
Error 1	12
Sub-total	19
Cylinder Speed (C)	2
Feed Rate (F)	2
Moisture Content x Cylinder Speed (M x C)	8
Moisture Content x Feed Rate (M x F)	8
Cylinder Speed x Feed Rate (C x F)	4
Moisture Content x Cylinder Speed x Feed Rate (MxCxF)	16
Error	120
Total	179

4. FACILITIES

General.

The experiment was carried out using the facilities of the Department of Agricultural Engineering, University of Alberta. The facilities included a stationary threshing unit, cleaning units, measuring instruments, and a conditioning room for obtaining the desired moisture content of the crop.

Conditioning Room.

The temperature and humidity in the conditioning room were controllable within a temperature range of 40 to 85^{o}F and a relative humidity range of 20 to 90%. These ranges will produce a range of moisture content at temperatures (23) which will avoid deterioration of the grain and straw from mold and insects.

The conditioning room had a floor area of 500 sq ft. An 8 ft by 8 ft door facilitated transfer of sheaves. The crop was kept in the conditioning room at a specific temperature and humidity until the required moisture content was obtained.

Temperature and Humidity of Conditioning Room.

The humidity in the conditioning room was maintained by discharging steam directly into the room (23). The entrained condensate in the steam was removed prior to discharge. A small circulating fan aided in the distribution of the steam in the conditioning room. A Johnson HC 4550 electronic room humidity controller (23) was used which has a range of 20 to 90% RH with a sensitivity of ± 5%. The room temperature was maintained using a steam to hot air heat exchanger. A Johnson HC 4550 electronic room thermostat (23) was used which has the range of 40 to 85^{0} with a sensitivity of $\pm 5^{0}$.

Threshing Unit.

The stationary threshing unit used for the experiment, except for the main drive, has been described by Vas and Harrison (36). Most component parts are commercially available, specifically being those used in the Massey-Ferguson 205 self-propelled combine. A schematic diagram by Vas and Harrison (36) is shown in Figure 1 and an overall view of the threshing unit, excluding the electric motor, in Figure 2. The specifications of the components of the threshing unit are given in Appendix 3.

Cleaning Units and Head Thresher.

The main cleaning unit consisted of a commercial fanning mill with the addition of a vibratory screen. The addition was required in order to adequately process the large quantity of straw. A schematic diagram by Vas (35) is shown in Figure 3 and the fanning mill in Figure 4. The other cleaning unit is a small fanning mill shown in Figure 5. The head thresher has a spike-tooth cylinder, 4 1/2 inches in diameter and 6 inches wide (Figure 6).

Thermo-Hygrograph.

A thermo-hygrograph (33) was used to record the temperature and humidity. It is a robust, simply constructed but reliable instrument. The temperature sensitive element is a laminated strip of two metals having a different coefficient of linear expansion. The humidity sensitive element is a cluster of specially prepared human hair that has the property of altering lengths for changes in relative humidity

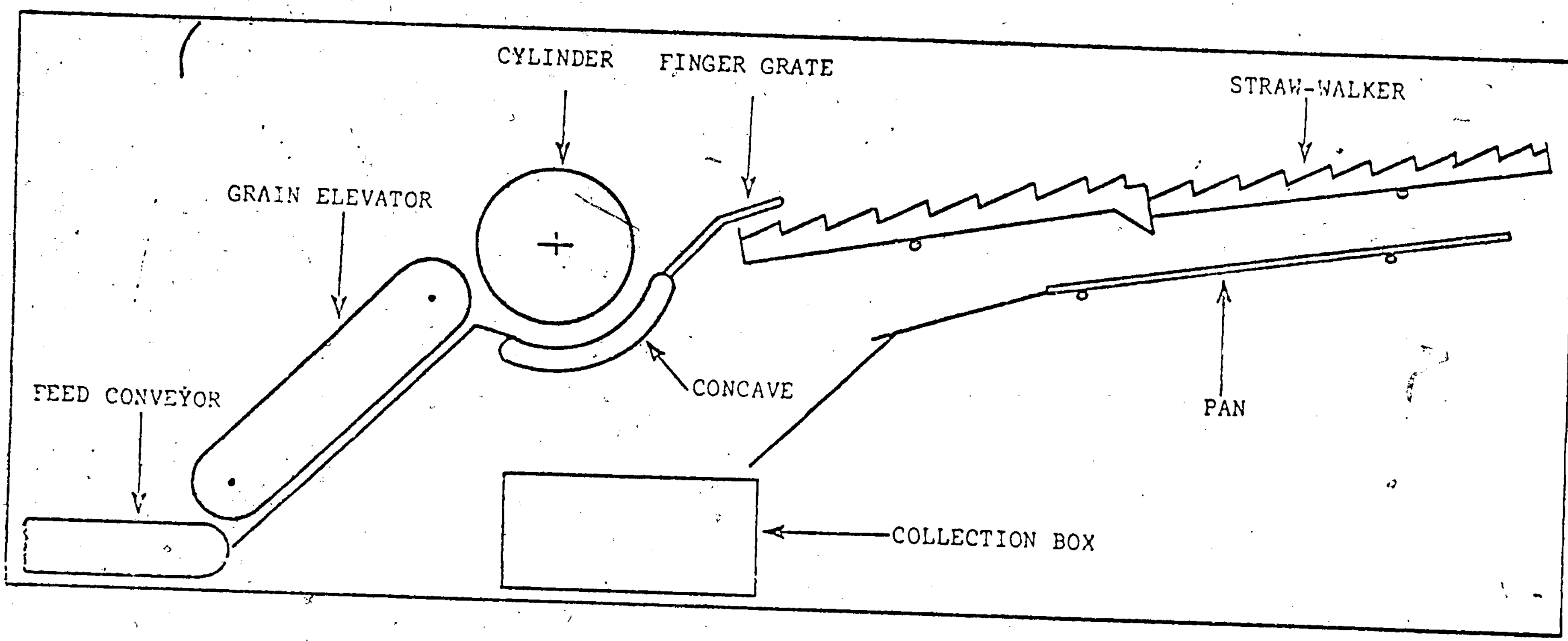


Figure 1: Schematic diagram showing the components of the laboratory threshing unit. (35)

Figure 2: The laboratory threshing unit.

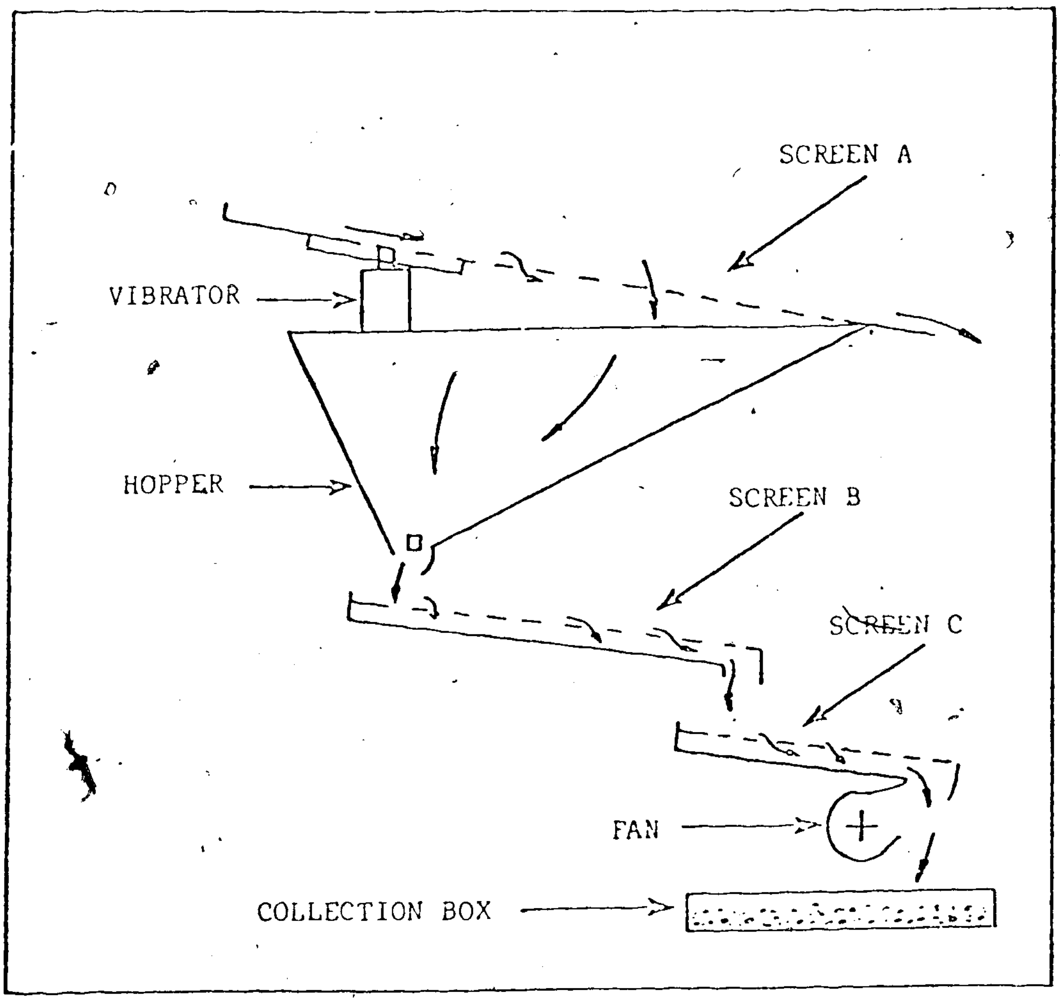


Figure 3: Schematic diagram showing the series of screens used in cleaning the grain sample. (35)

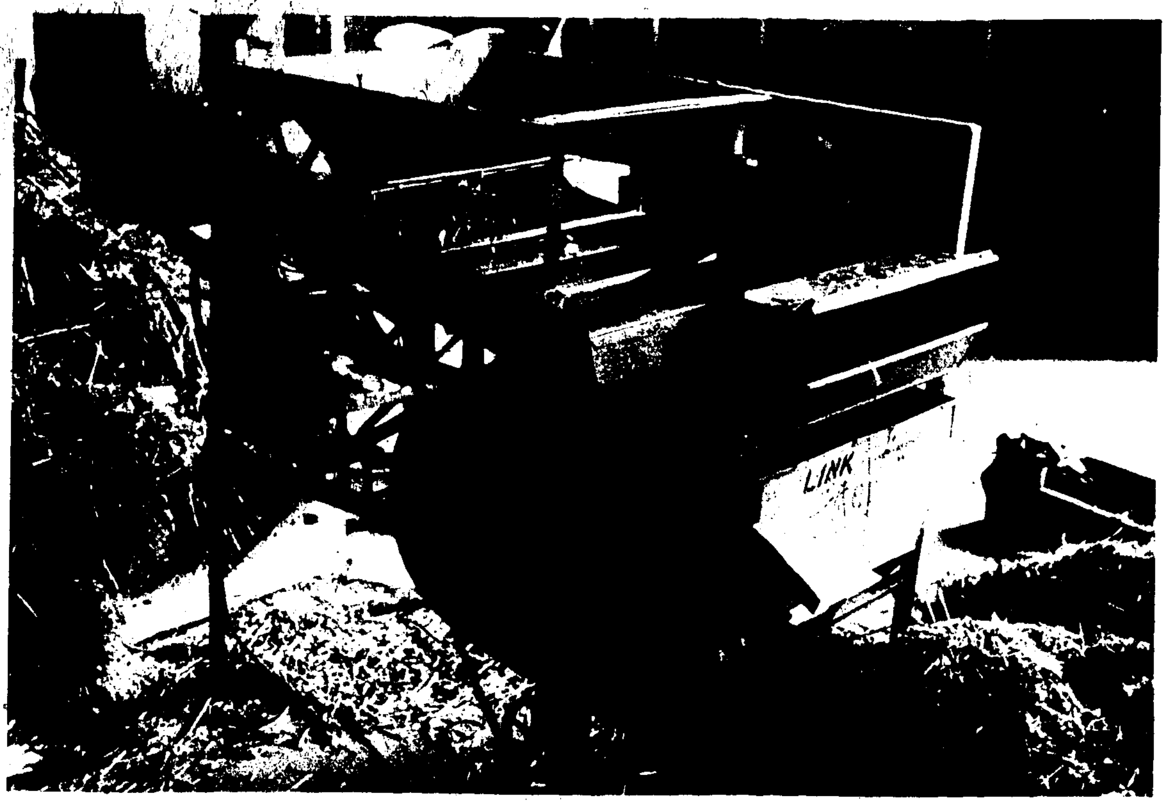


Figure 4: The fanning mill.

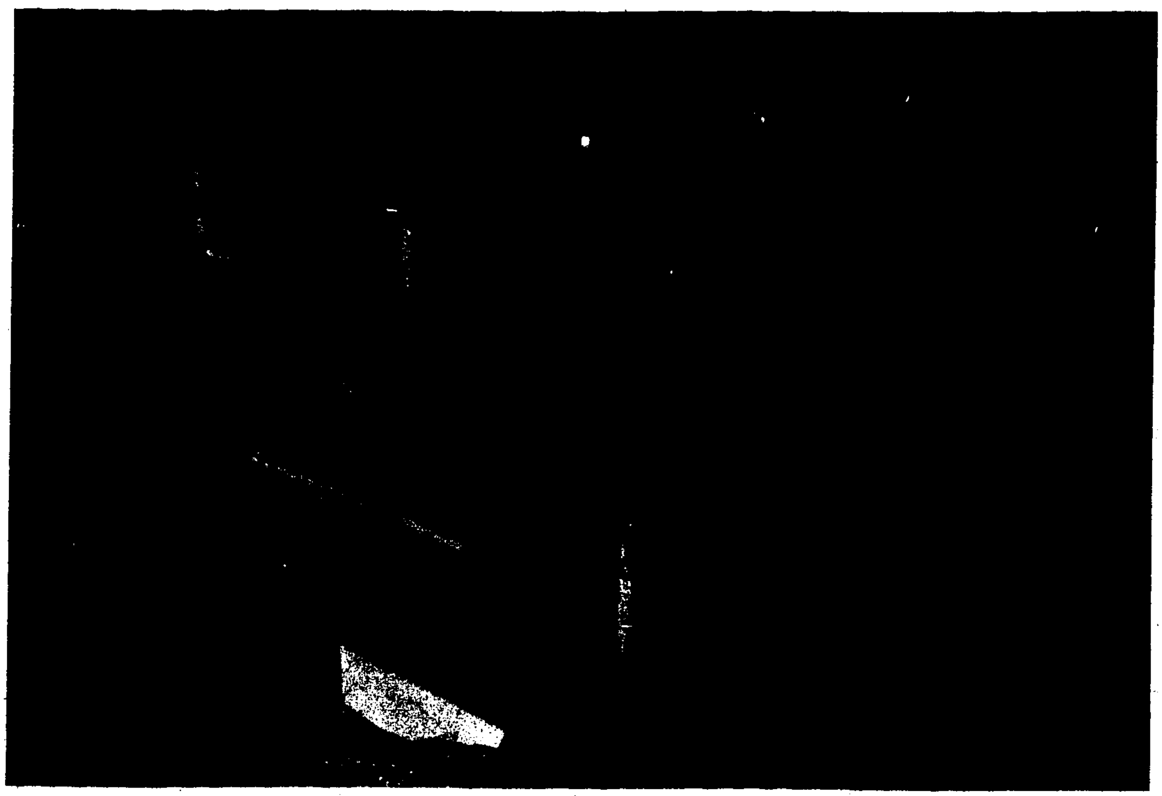


Figure 5: The clipper cleaner.

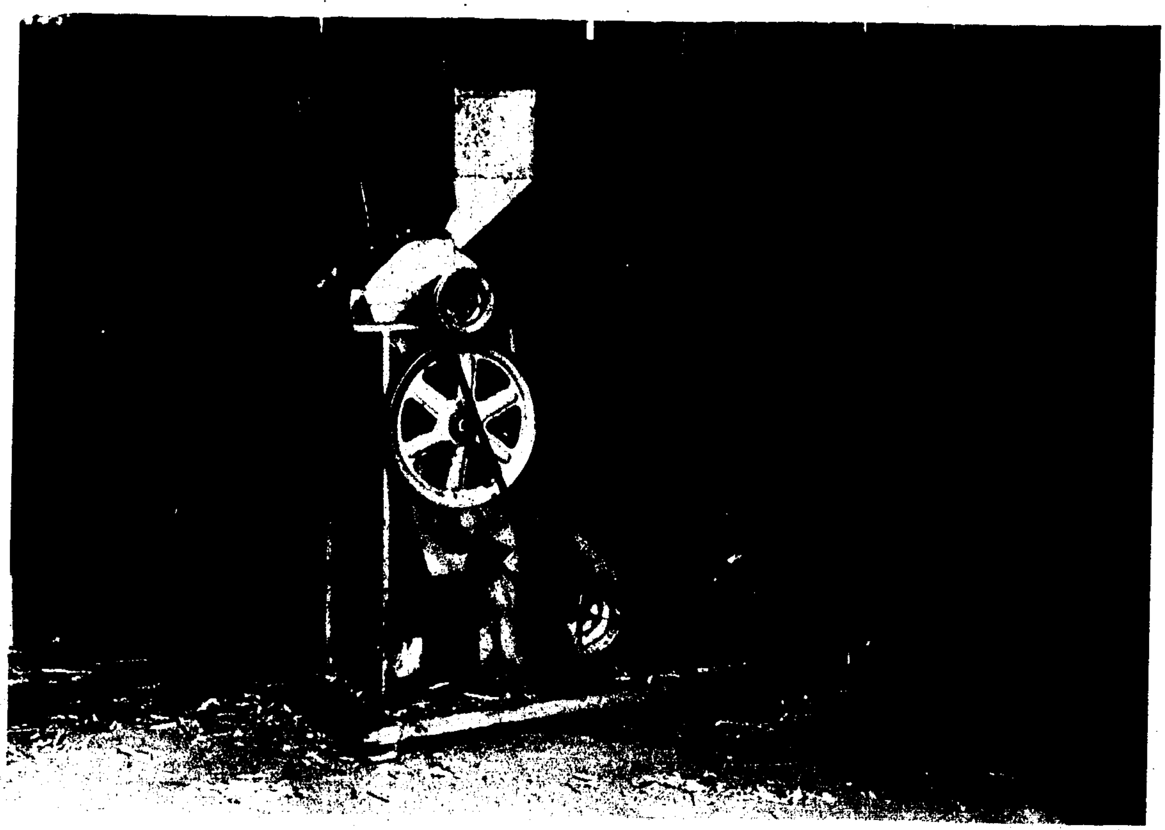


Figure 6: The head threshing unit.

but is relatively insensitive to changes in temperature. The range of the recording chart was 0 to 100^{o}F and 0 to 100% RH.

Other Instruments.

A conical gravity flow sample divider was used for obtaining samples of grain. For moisture determinations, a forced draft oven was used, but for quick determination of moisture content, a Halross Model 919 (27) was used.

5. MATERIALS AND METHODS.

Threshing Material.

The cultivar used for the experiment was the hard red spring wheat, Park. The characteristics of the cultivar (34) are early maturity and good resistance to lodging and shattering. Park is considerably easier to thresh than other common cultivars, such as Thatcher. The crop was cut with a binder in the year prior to the experiment and stored outside under a plastic cover. The straw to grain ratio ranged between 1.2:1 to 2.8:1. The straw-to-grain ratio for each trial is given in Appendix 10.

Sample Selection.

The sheaves were hauled from the outside storage to the harvesting laboratory and stacked on wooden pellets. The stacks were numbered and by using a random number table, twenty sheaves were taken by random from the different stacks.

Crop Conditioning.

The selected sheaves were placed on racks in the conditioning room. Using the American Society of Agricultural Engineers Data 245.1 (2), the appropriate temperature and relative humidity were determined and used to set the thermostat and humidistat to obtain the required moisture content of the crop.

Much difficulty was experienced in obtaining the 20% moisture content during the month of November. It was not possible to obtain a high relative humidity at a high temperature because of the low ambient temperature. Moisture condensed on the walls of the room because the wall temperature was lower than the air temperature inside the room. The humidistat responded with additional steam but the added moisture immediately condensed on the walls. In addition, a high relative humidity and temperature favours mold development. To avoid these problems, the conditioning unit was turned off and the doors opened. In the month of November, the mean ambient temperature in the Edmonton area is 24.5^{0}F and the mean relative humidity is 74% (28). This temperature and humidity is such that the equilibrium moisture content of wheat is 20 to 22%. Within 3 days of exposure to ambient temperature and humidity, a moisture level of 22% was obtained. The moisture level was reduced to 20% by closing the doors and keeping the temperature above the freezing point for a few days.

Threshing Unit.

The threshing unit was adjusted in accordance with the nine treatment combinations given in Appendix 1. The cylinder speed and the feed rate for each trial were obtained by changing the sprockets in the power transmission units. The front concave clearance was 11/16 of an inch with 1/8 for the rear as suggested by Vas (35). The quantity of crop for each run was 50 pounds a value that was suggested by Vas (35) as being adequate.

Initial Run.

The procedure for each run was to bring a number of sheaves from the conditioning room and then weigh out 50 lb using a platform scale. The crop was then spread uniformly on the whole length of the conveyor with the heads-up and head-first configuration. The cylinder of the threshing unit was engaged and, when it had obtained the specified speed, the feed conveyor was started. The grain and other threshed material passing through the straw walkers was collected and subsequently separated using the cleaning units (see Appendix 4). The partially threshed heads obtained from the cleaning units were threshed in the head thresher and the free grain added to W2, the grain normally lost (see Appendix 5). A 5 lb sample was taken from the W1 sample and, by using a sample divider, a 100 gram sample was obtained for analysis of the kernel damage.

Rethreshed Run.

The straw and partially threshed heads coming over the straw walkers were collected and subsequently spread uniformly on the conveyor and rethreshed with the threshing unit. The free grain and other threshed material passing through the walkers was collected and subsequently separated with the cleaning units and added to W2 (normally lost). The partially threshed heads obtained from the cleaning units were threshed in the head thresher with this grain also being added to W2. The total weight of the clean grain (W1 + W2) for each trial is given in Appendix 6.

Kernel Damage.

Any damaged kernels that were visible to the naked eye, were removed from the samples taken for the analysis of kernel damage. The weight of the damaged kernels was expressed as a percent of the 100 gram sample (Appendix 7).

6. RESULTS

Analysis of Variance - Kernel Damage.

The analysis of variance for kernel damage is given in Table 2. The main effects of kernel damage due to moisture content and cylinder speed are highly significant but that for the feed rate is not. The means are given in Table 5. The moisture content x cylinder speed interaction (M x C), the moisture content x feed rate interaction (M x F) and the cylinder speed x feed rate interaction (C x F) are all significant. The moisture content x cylinder speed x feed rate interaction (M x C x F) is significant but only at the 0.05 probability level.

The interactions noted above indicate that the damage response for each of the three factors (moisture content, cylinder speed and feed rate) were not independent of the level of the other two factors. Figure 7 indicates that the damage response was similar for all levels of cylinder speed. For example, the least damage occurred at 20% moisture content for all cylinder speeds. On the other hand a minimum damage occurred at a 14% moisture content for the 700 and 900 rpm levels but a similar minimum occurred at 16% for the 1100 rpm level.

As for the feed rate, a similar situation exists; that is, the damage response was similar for all levels of feed rate with important exceptions (Figure 8).

The interaction of cylinder speed and feed rate is illustrated in Figure 9 with the responses at 1100 rpm being opposite to that obtained at a cylinder speed of 700 rpm.

TABLE 2: ANALYSIS OF VARIANCE (KERNEL DAMAGE).

Source of Variation	Degree of Freedom	Sum of Squares	Mean Squares	F
R = Replicate	3	0.898	0.299	0.75
M = Moisture	4	46.538	11.635	29.47**
Error 1 = (Replicate x Moisture)	12	4.736	0.394	
Sub-Total	19			
C = Cylinder speed	2	32.458	16.229	76.24**
F = Feed rate	2	0.243	0.121	0.57
C x F	4	3.630	0.907	4.26 **
C x M	8	18.91	2.363	11.10 **
F x M	8	5.261	0.657	3.08 **
C x F x M	16	6.650	0.416	1.95 *
Error 2	120	25.543	0.212	
Total	179			

* Significant at 0.05 probability level.

** Significant at 0.01 probability level.

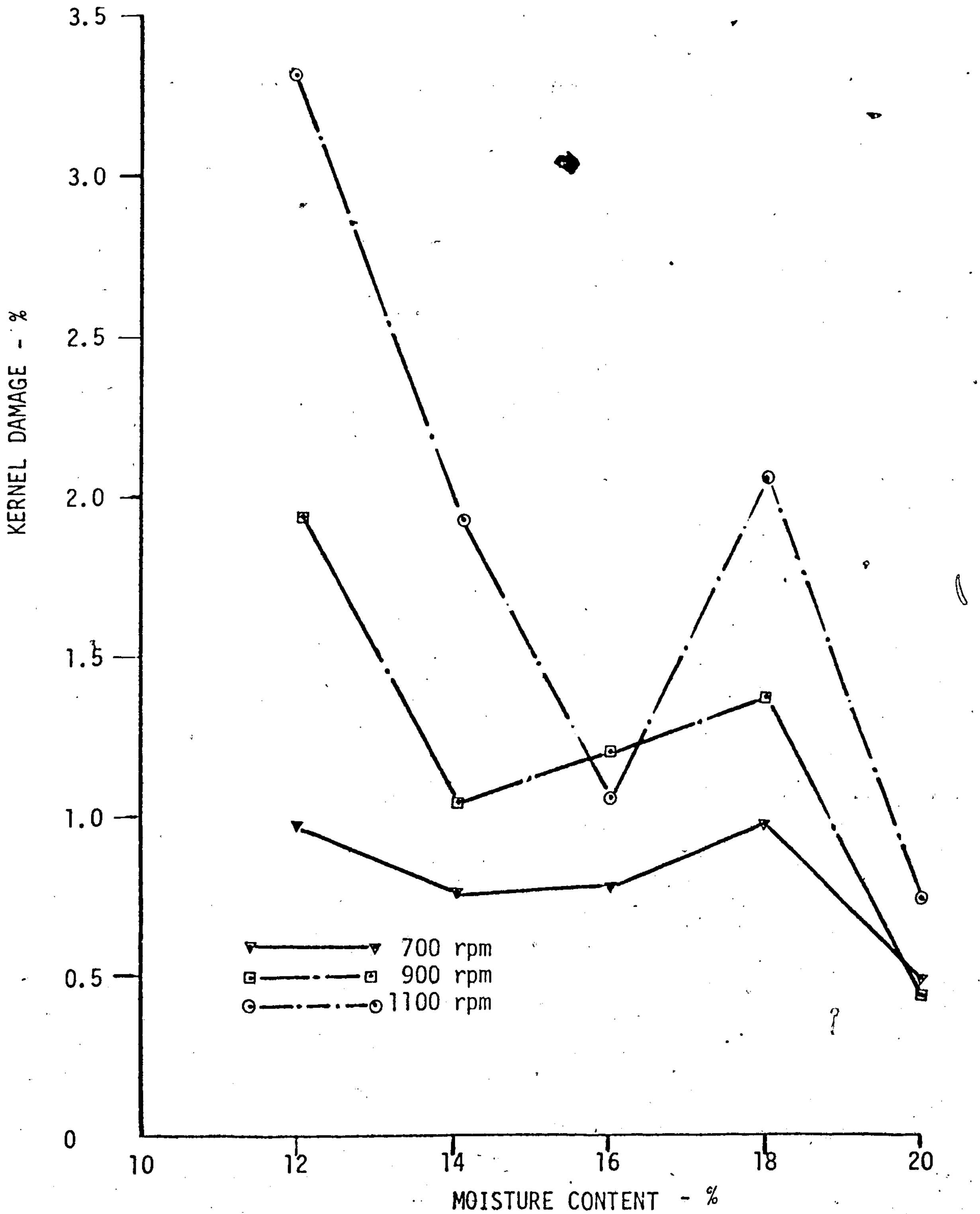
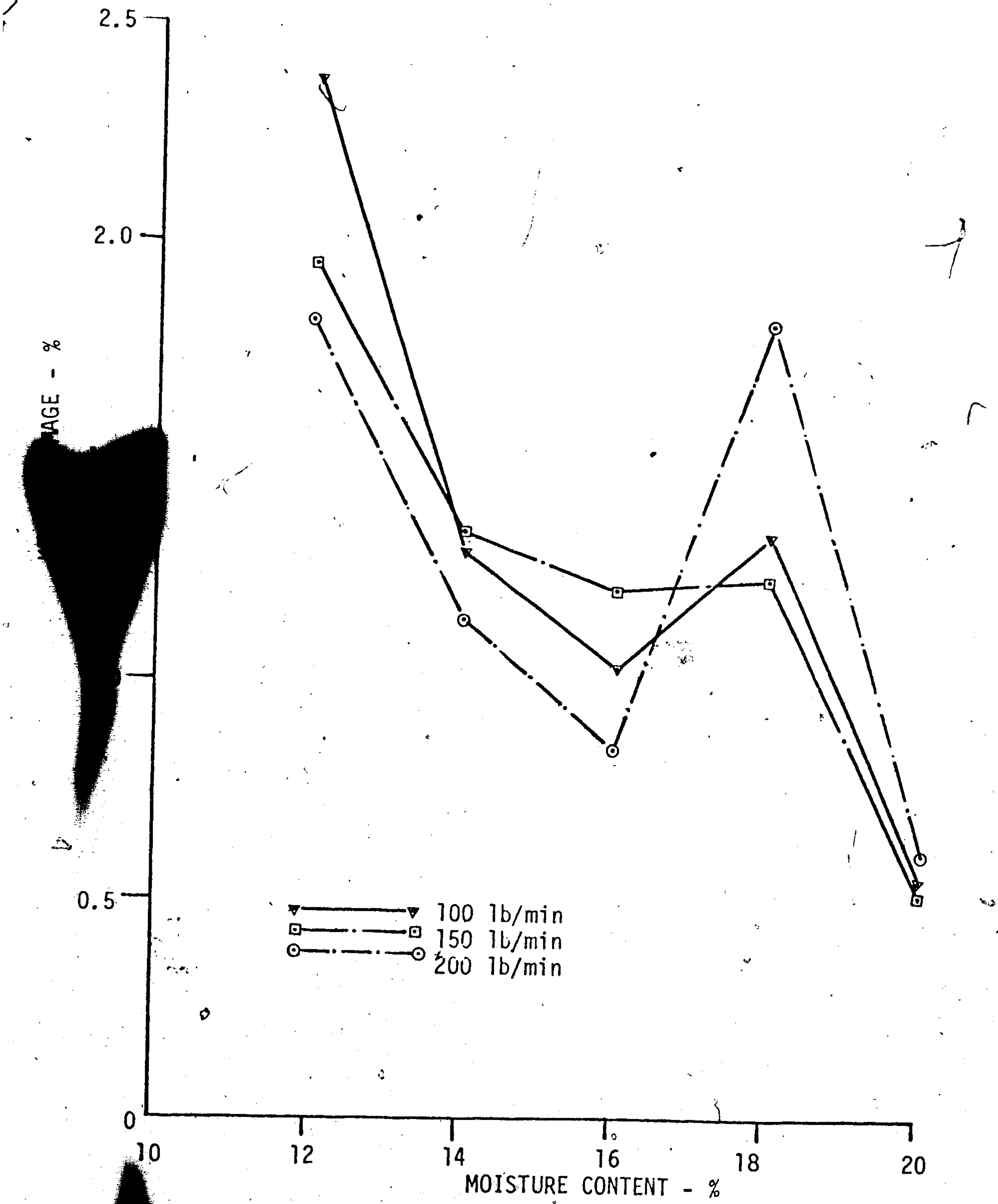


Figure 7 : The effect of moisture content x cylinder speed (M x C) interaction on kernel damage.



igure 8: The effect of moisture content x feed rate interaction (M x F) on kernel damage.

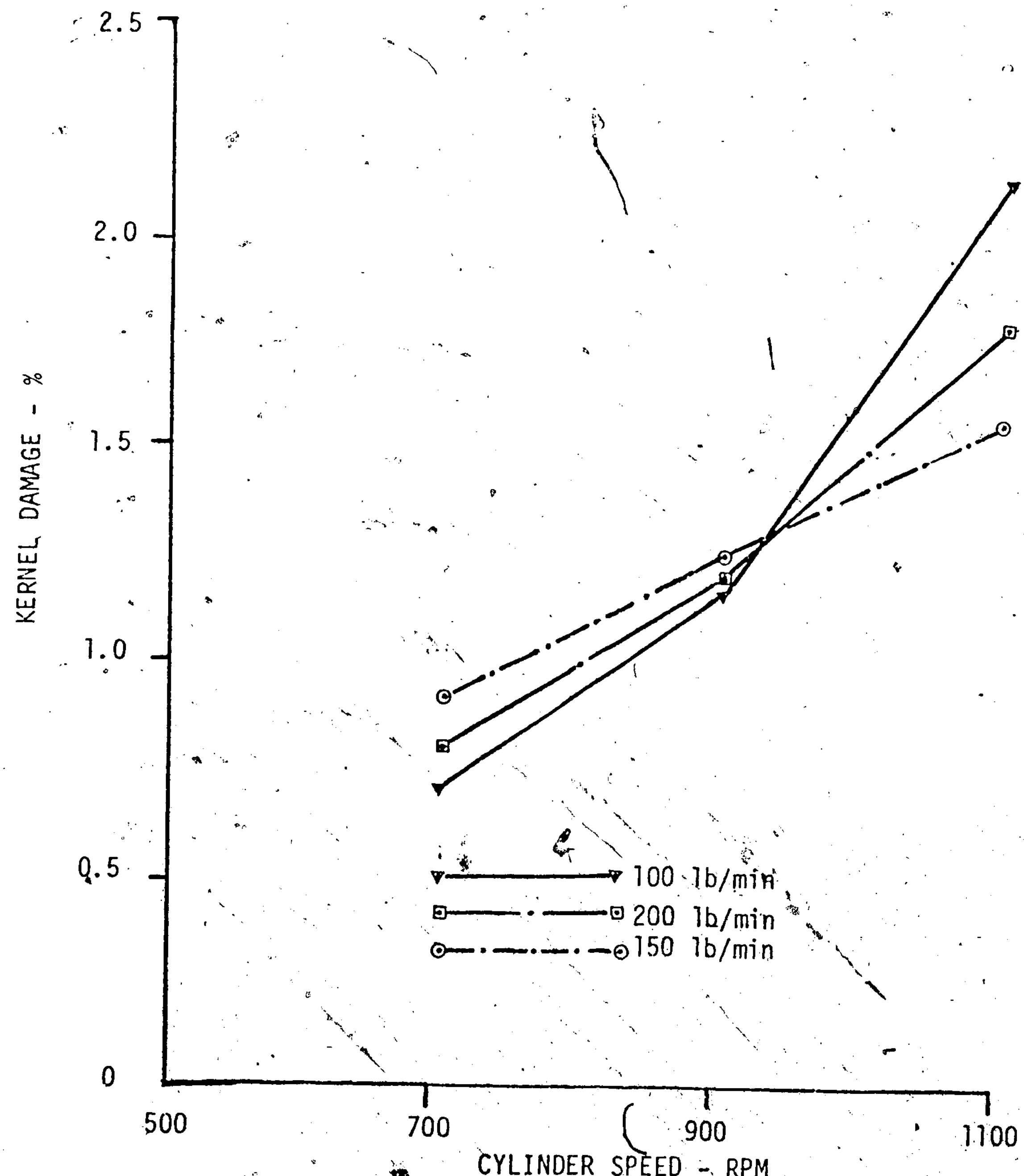


Figure 9: The effect of cylinder speed x feed rate interaction (C x F) on kernel damage.

Analysis of Variance - Threshability.

The main effects of threshability due to moisture content and cylinder speed are significant (see Table 3). The means are given in Table 5. As expected the maximum threshability occurred with the lowest moisture level (12%) whereas the minimum occurred for the highest moisture content (20%). Except for the 18% moisture content, the threshability decreased with an increase of moisture content, a trend similar to that for damage. The threshability increased (Table 5) with an increase of cylinder speed, with the greatest threshability occurring at 1100 rpm and the least at 700 rpm.

Analysis of Variance - Total Wastage.

With regard to total wastage, the significant main effects were due to the moisture content and the cylinder speed (see Table 4). There is only one significant interaction and that is the cylinder speed x moisture content. An optimum moisture content may exist in the 12 to 16% moisture content but it matters little if the moisture content is less than 20% (Table 5). The response of total wastage due to cylinder speed was opposite to that obtained by Vas and Harrison (36). On the other hand, the moisture content used by Vas and Harrison was 10% and there exists a possibility that had 10% been included in this experiment the response may have been opposite to that obtained at 12% above.

TABLE 3 : ANALYSIS OF VARIANCE (THRESHABILITY).

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F
R = Replicate	3	5.179	1.726	0.48
M = Moisture	4	164.59	41.146	11.60**
Error 1 = (Replicate x Moisture)	12	42.56	3.54	
Sub-Total	19			
C = Cylinder speed	2	782.55	391.27	111.47**
F = Feed rate	2	8.03	4.015	1.14
C x F	4	11.287	2.8218	0.80
C x M	8	29.937	3.74	1.06
F x M	8	28.694	3.58	1.02
C x F x M	16	49.833	3.1146	0.88
Error 2	120	421.66	3.51	
Total	179			

** Significant at 0.01 probability level.

TABLE 4: ANALYSIS OF VARIANCE (TOTAL WASTAGE).

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F
R = Replicate	3	4.69	1.56	1
M = Moisture Content	4	50.03	12.51	3.98*
Error 1 = (Replicate x Moisture Content)	12	38.81	3.23	
Sub-Total	19			
C = Cylinder Speed	2	512.03	256.02	68.76**
F = Feed Rate	2	8.50	4.25	1.08
C x F	4	12.90	3.22	1
C x M	8	72.47	9.06	2.48*
F x M	8	39.64	4.95	1.33
C x F x M	16	63.02	3.94	1.06
Error 2	120	446.77	3.72	
Total	179			

* Significant at 5% probability level.

** Significant at 0.5% probability level.

TABLE 5: DAMAGED AND UNTHRESHED GRAIN AND TOTAL LOSS MEANS.

Moisture Content (%)	Damaged* (%)	Unthreshed** (%)	Total** (%)
12	2.09	6.73[c]	8.69[a]
14	1.25[a]	7.39[bc]	8.57[a]
16	1.02[a]	8.51[ab]	9.44[ab]
18	1.46[a]	7.94[bc]	9.29[ab]
20	0.55	9.52[a]	10.02[b]
Cylinder Speed (rpm)			
700	0.79	10.79	11.50
900	1.20	7.51	8.62
1100	1.83	5.76	7.49
Feed Rate (lb/min)			
100	1.32[a]	8.00[a]	9.23[a]
150	1.24[a]	7.77[a]	8.93[a]
200	1.25[a]	8.29[a]	9.46[a]

a, b, c - means with the same superscripts in the same column are <u>not</u> significantly different at the 1% probability level.

* Percentage of threshed grain.

** Percentage of all grain.

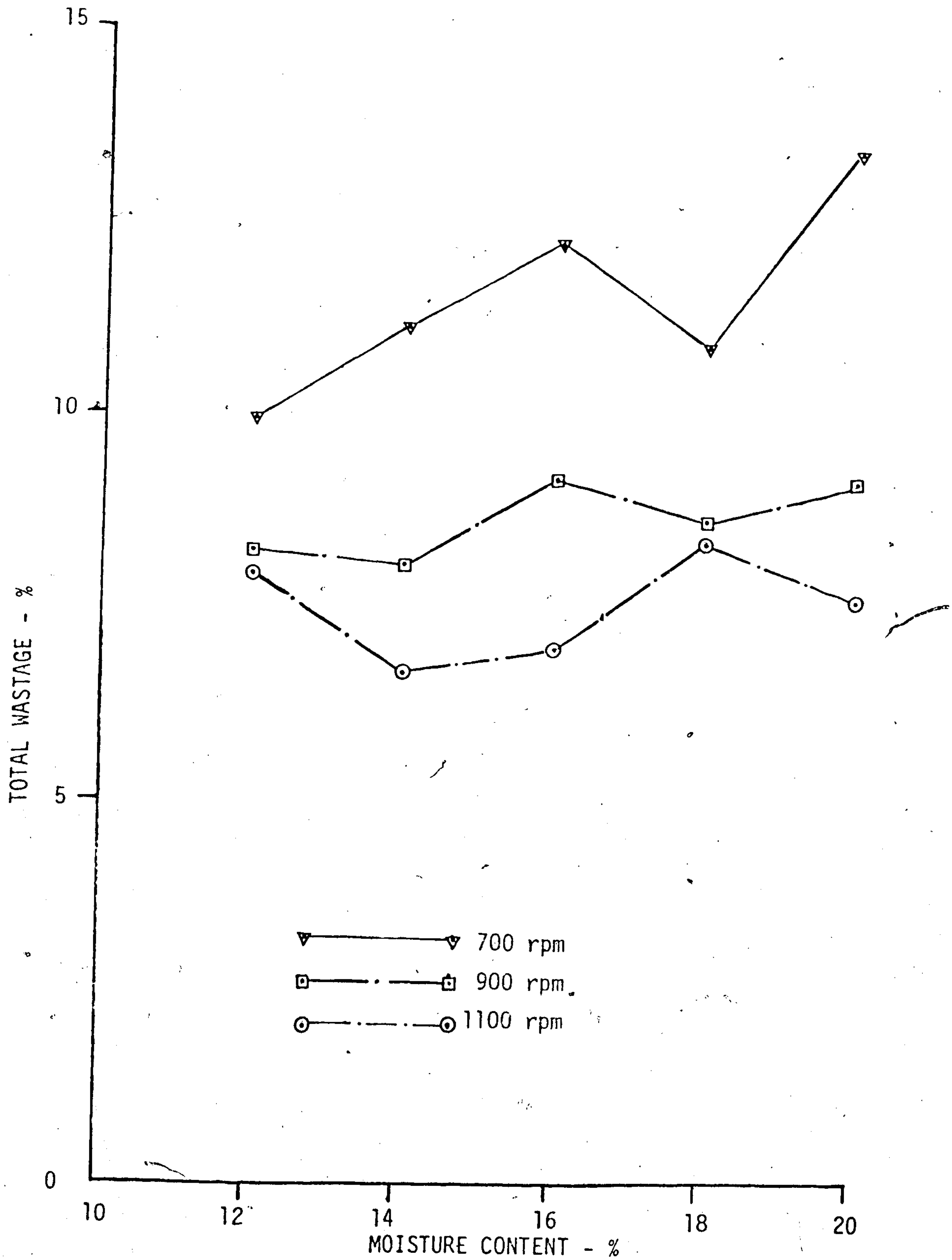


Figure 10: The effect of moisture content x cylinder speed interaction (C x F) on total wastage.

7. DISCUSSION OF RESULTS

Cylinder Speed.

Arnold (4) and others (8,11,12,26) have stated that in the threshing process, an ear of grain is subjected to one or more impacts by the cylinder bar and it is the impact that dislodges the kernels. Most researchers (3,4,5,10,11) have found that an increase in the cylinder speed increases the amount of kernel damage, as was obtained from this study. Vas and Harrison (36) suggest that the relationship between the cylinder speed and the kernel damage is an impact process or model. An elaboration of this model is as follows:

$$mv_1 + \text{impulse} = mv_2 \text{ or}$$

$$F\,t = m(v_2 - v_1)$$

where F is the force of impulse or impact

t is the duration (time) of the impact

m is the mass of the ear

v_1 is the velocity of the ear prior to impact

v_2 is the velocity of the ear after impact

The cylinder velocity and v_2 are essentially the same and v_1 is so small relative to v_2 it may be neglected; that is,

$$F = mv/t$$

If the cylinder speed is doubled t is reduced by a half or

$$F' = m(2v)/t/2$$

$$= 4mv/t$$

$$F' = 4F$$

In other words, the impact is the squdre of the change in the cylinder speed. At 700 rpm the damage obtained was 0.8% whereas at 1100 rpm it was 1.8%. The increase in damage is in the ratio of 1.82/.79 or 2.3 which is equivalent to the square of the increase in the cylinder bar velocity,

$$(1100/700)^2 = 2.4.$$

With regard to threshability, Vas and Harrison (36) have suggested that the impact model also may account for the decrease in the amount of grain left in the ear with an increase in the cylinder speed; that is, the mechanism to detach the kernel from the ear may be similar to the mechanism of kernel damage. At 700 rpm, the grain left in the ear in this experiment was 10.8% (100 - 89.2) whereas at 1100 rpm it was 5.8% (100 - 92.5). The decrease is slightly more than one-half which only approximates the reciprocal of $(1100/700)^2$. In fact the reciprocal of 1100/700 provides an equally accurate estimate of the decrease of the grain left in the ear. Though these calculations suggest that the impact model does not apply for threshability, in point of fact, it may. The causal relationship between threshability and cylinder speed is likely to be affected by the variability in the attachment of the kernel to the ear. For kernel damage the kernel strength may be quite uniform from kernel to kernel and, as a result, the damage is almost exclusively a function of a change in the cylinder speed. With regard to threshability, if the attachment is uniform, the threshability will be an exclusive function of the cylinder speed. The evidence from the results is that to achieve 100% threshability; that is remove all of the kernels from the ear, a cylinder speed in excess of 2000 rpm might be required. Apparently some kernels are difficult to dislodge from the ear.

The damaged grain during the cleaning process is separated and treated as a loss. This loss is known as dockage. Thus the grain damage does not affect the seed or commercial grain

Feed Rate.

Vas and Harrison (36) experienced a reduction in the damage with an increase in feed rate and attributed this relationship to a cushioning effect or model at the higher feed rate. Similar results were obtained in this study but only at the 12% moisture content level. With regard to threshability, Vas and Harrison (36) suggested that a frictional model might be involved along with the cushioning model, with the former off-setting the effects of the latter. The same may apply with regard to kernel damage at moisture contents of 14% or higher. In any event,threshability, and at higher moisture contents, damage, are not affected by the feed rate.

Moisture Content.

Bilanski (13) found that greater energy was required to break wet kernels than those having a lower moisture content. Similarly Zoerb and Hall (39) found that the energy required to damage grain by impact increases with an increase of moisture content, but noted an exception at a moisture content of 18% (wet basis), which agrees with the results of this study. Zoerb and Hall (39) commented that there is an increase in the shear strength of the kernel at this moisture content.

This apparent increase in the shear strength may be due to a change in a failure mechanism of the kernel which is similar to the change suggested by Vomcil and Chancellor (37) for soil. They (37) suggested that a change in failure mechanism occurs when soil changes from a plastic to a brittle state.

For a moisture content greater than 18%, it is apparent that the kernels are quite soft. They will deform without exhibiting any visible fracture. The change in the shape of the kernel or déformation was readily seen.

Total Wastage.

The response of damage and unthreshed grain was such that when these effects were added together the total loss was largely independent of the moisture content; that is, with respect to grain loss, there is no advantage to thresh the cultivar Park at any particular moisture content within the range of 12 to 18%. With regard to the cylinder speed, however, the optimum is very much a function of the moisture content. For the cultivar in question at a moisture content of 10%, Vas and Harrison (36) indicated that the optimum cylinder speed should be less than 800 rpm. For the same cultivar but at a moisture content of 12% or greater, the optimum cylinder speed should be 1100 rpm or greater. It is apparent that the optimum changes abruptly between 10 and 12% moisture content. It is worthwhile to note that the optimum cylinder speed of less than 800 rpm is less than the minimum recommended by combine manufacturers and that 1100 rpm is near the maximum suggested by the manufacturers.

8. SUMMARY AND CONCLUSIONS

The amount of kernel damage in threshing is directly related to the square of the velocity of the cylinder bar. Except for the 18% moisture content, the damage decreased with an increase in moisture content. The complex relationship is attributed to a change in the failure mechanism within the kernel which seemingly is associated with a change in the state of the kernel from brittle to plastic.

With regard to threshability, it also decreased as the moisture content increased with the same exception at 18% moisture content. The form of the relationship is identical to the form noted with respect to the kernel damage and, therefore, the change in the failure mechanism of the attachment would also seemingly be associated with a change in state from brittle to plastic.

A summary of the observations are:

Kernel damage increases with cylinder speed, decreases with moisture content, and is independent of the feed rate.

At low moisture contents (less than 18%) the grain seems to be brittle because the kernels fracture and break into pieces.

At high moisture content (greater than 18%) the grain seems to be plastic because the kernels change shape without fracturing.

The total wastage increases with the cylinder speed but is largely independent of the moisture content.

The optimum cylinder speed with regard to total wastage should be 1100 rpm or greater for all moisture contents from 12 to 20% which is greater than that usually recommended.

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10. APPENDICES

APPENDIX I: LIST OF TREATMENT COMBINATIONS.

MOISTURE CONTENT (X_M) - % - 12%, 14%, 16%, 18%, 20%.

Trial No.	Cylinder Speed (X_C - rpm)	Feed Rate (X_F - lbs/min)
1	700	100
2	700	150
3	700	200
4	900	100
5	900	150
6	900	200
7	1100	100
8	1100	150
9	1100	200

APPENDIX 2 : RANDOMIZED ORDER OF THE TRIALS.

Replicate 1	Replicate 2	Replicate 3	Replicate 4
5	8	2	6
9	2	3	7
8	4	8	3
1	9	6	5
3	1	1	8
7	3	5	9
4	6	9	4
6	5	4	1
2	7	7	2

APPENDIX 3 : SPECIFICATIONS OF THRESHING AND CLEANING UNITS.

	THRESHING UNIT	SPECIFICATIONS
CYLINDER		
	Type	Rasp bar
	Number of bars	8
	Diameter	22 in.
	Width	26 in.
	Speed	205-1150 rpm
CONCAVE		
	Type	Open grate
	Clearance - Front	1 - 1/4"
	Clearance - Rear	5/8"
BEATER (BEHIND CYLINDER)		
	Diameter	15"
	Number of blades	4
	Speed	705 - 710 rpm
STRAW WALKERS		
	Number	3
	Type	Single step open bottom
	Throw	2"
	Walker shaft span	
	Speed	195 rpm
	Width (per walker)	30 in.
	Length	130 in.
FEEDER CHAIN		
	Length	118 in.
	Width	24 in.
	Speed	350 rpm
FEED CONVEYOR		
	Length	50 ft.
	Width	3 ft.
	Speed	100, 150, 200 ft/min

CLEANING UNIT

CLEANING SCREEN	SPECIFICATIONS
Number of Screens	3
Screen A	
Length	26 in.
Width	21 in.
Opening	3/8"x7/8"
Pitch	10^0
Screen B	
Length	24 in.
Width	24 in.
Number of Brushes	4
Opening	14/16 in.
Screen C	
Length	15 in.
Width	9 in.
Opening	16/64 in.

HEAD THRESHER	
Type	Spike tooth
Diameter	4 1/2 in.
Width	6 in.
Speed	500 - 1250 rpm

APPENDIX 4 WEIGHT OF INTIAL GRAIN CATCH (W1) LBS

MOISTURE CONTENT -12%

TRIAL NO	CYLINDER SPEED	FEED RATE	W1 REPLICATES I	II	III	IV
1	700	100	18.06	17.87	19.25	17.52
2	700	150	17.49	17.67	19.60	17.55
3	700	200	17.41	17.10	16.63	18.57
4	900	100	18.90	19.47	19.92	19.99
5	900	150	18.26	18.72	19.62	19.22
6	900	200	19.45	19.30	18.00	18.89
7	1100	100	19.25	18.60	18.60	20.10
8	1100	150	19.73	19.54	19.78	19.62
9	1100	200	20.17	20.79	19.24	19.80

MOISTURE CONTENT -14%

TRIAL NO	CYLINDER SPEED	FEED RATE	W1 REPLICATES I	II	III	IV
1	700	100	18.86	18.04	18.50	17.60
2	700	150	19.04	17.60	18.94	17.80
3	700	200	17.16	18.52	19.05	18.06
4	900	100	18.41	20.54	19.70	18.20
5	900	150	18.50	19.00	19.90	19.45
6	900	200	19.47	20.08	18.92	20.06
7	1100	100	19.28	19.80	19.94	20.14
8	1100	150	18.64	21.82	20.88	20.62
9	1100	200	18.10	20.96	20.52	18.94

MOISTURE CONTENT -16% W1

TRIAL NO	CYLINDER SPEED	FEED RATE	REPLICATES I	II	III	IV
1	700	100	17.20	21.26	17.57	18.36
2	700	150	18.65	18.30	15.62	16.48
3	700	200	17.51	16.46	11.76	17.65
4	900	100	20.30	19.32	17.35	19.36
5	900	150	20.40	18.82	17.92	17.85
6	900	200	19.34	19.76	17.84	17.80
7	1100	100	19.55	20.56	19.04	21.02
8	1100	150	20.36	19.84	19.10	20.42
9	1100	200	17.16	24.54	18.84	20.10

MOISTURE CONTENT -18% W1

TRIAL NO	CYLINDER SPEED	FEED RATE	REPLICATES I	II	III	IV
1	700	100	18.05	15.36	11.54	17.94
2	700	150	17.30	17.25	18.10	17.14
3	700	200	14.80	16.12	15.49	15.30
4	900	100	18.60	18.90	17.10	19.30
5	900	150	18.17	17.56	16.64	18.33
6	900	200	18.62	16.23	15.67	17.56
7	1100	100	19.06	18.82	19.14	16.56
8	1100	150	19.20	20.49	16.92	18.45
9	1100	200	19.30	16.80	17.82	17.38

MOISTURE CONTENT -20% W1

TRIAL NO	CYLINDER SPEED	FEED RATE	REPLICATES I	II	III	IV
1	700	100	15.64	16.30	15.75	17.20
2	700	150	16.08	15.66	16.04	18.26
3	700	200	15.26	14.32	15.64	14.58
4	900	100	18.30	15.96	17.81	17.91
5	900	150	17.82	16.94	16.34	18.16
6	900	200	17.40	17.58	16.60	17.20
7	1100	100	17.62	17.22	17.88	15.46
8	1100	150	14.72	18.60	16.54	18.22
9	1100	200	16.50	17.60	18.50	17.88

APPENDIX 5 . WEIGHT OF RETHRESH GRAIN CATCH (W2) - LBS

MOISTURE CONTENT -12% W2

TRIAL NO	CYLINDER SPEED	FEED RATE	REPLICATES I	II	III	IV
1	700	100	2.15	2.23	1.64	1.22
2	700	150	1.90	2.00	1.10	1.92
3	700	200	1.35	2.27	1.70	1.81
4	900	100	1.52	1.50	1.17	1.33
5	900	150	1.40	1.17	1.25	1.26
6	900	200	1.41	1.40	0.92	1.22
7	1100	100	0.75	1.07	1.07	0.67
8	1100	150	1.10	1.15	0.72	1.20
9	1100	200	1.10	1.15	1.18	0.77

MOISTURE CONTENT -14% W2

TRIAL NO	CYLINDER SPEED	FEED RATE	REPLICATES I	II	III	IV
1	700	100	1.65	3.00	2.50	2.03
2	700	150	2.15	1.95	2.50	2.04
3	700	200	1.90	2.26	2.10	1.50
4	900	100	1.75	1.62	1.46	1.46
5	900	150	1.65	0.70	1.40	2.06
6	900	200	1.55	1.58	1.50	0.88
7	1100	100	1.20	1.30	0.70	1.40
8	1100	150	0.50	1.07	1.00	1.17
9	1100	200	0.42	0.94	1.02	1.22

MOISTURE CONTENT -16% W2

TRIAL NO	CYLINDER SPEED	FEED RATE	REPLICATES I	II	III	IV
1	700	100	2.54	1.76	2.08	1.53
2	700	150	2.42	2.25	2.50	2.34
3	700	200	2.51	2.60	1.86	2.23
4	900	100	1.68	1.72	2.47	1.56
5	900	150	1.11	1.59	1.74	2.36
6	900	200	1.42	1.38	1.42	1.40
7	1100	100	1.08	1.40	0.82	0.87
8	1100	150	1.12	1.12	0.95	0.95
9	1100	200	2.56	2.02	1.10	1.09

MOISTURE CONTENT -18% W2

TRIAL NO	CYLINDER SPEED	FEED RATE	REPLICATES I	II	III	IV
1	700	100	1.42	1.66	1.57	1.80
2	700	150	1.50	2.21	1.84	1.95
3	700	200	2.80	1.80	1.85	1.15
4	900	100	1.86	1.35	1.24	1.40
5	900	150	1.04	1.10	1.25	1.37
6	900	200	1.70	1.22	2.37	0.90
7	1100	100	1.86	1.20	0.97	0.92
8	1100	150	0.72	1.32	1.45	1.53
9	1100	200	0.81	1.70	1.34	1.35

MOISTURE CONTENT -20% W2

TRIAL NO	CYLINDER SPEED	FEED RATE	REPLICATES I	II	III	IV
1	700	100	2.40	2.57	2.46	2.48
2	700	150	2.09	1.00	2.61	2.76
3	700	200	2.04	2.72	2.43	2.79
4	900	100	1.72	1.82	1.55	1.73
5	900	150	1.70	1.13	2.02	1.81
6	900	200	1.22	1.64	1.81	1.79
7	1100	100	1.50	1.00	1.13	1.35
8	1100	150	0.88	1.12	1.73	1.42
9	1100	200	1.50	1.34	1.25	1.09

APPENDIX 6 TOTAL WEIGHT (WT) -LBS

MOISTURE CONTENT -12% WT

TRIAL NO	CYLINDER SPEED	FEED RATE	REPLICATES I	II	III	IV
1	700	100	20.20	20.10	20.80	18.70
2	700	150	19.30	19.60	20.70	19.40
3	700	200	18.70	19.30	18.30	20.30
4	900	100	20.40	20.90	21.00	21.30
5	900	150	19.60	19.80	20.80	20.40
6	900	200	20.80	20.70	18.90	20.10
7	1100	100	20.00	19.60	19.60	20.70
8	1100	150	20.80	20.60	20.50	20.80
9	1100	200	21.20	21.90	20.40	20.50

MOISTURE CONTENT -14% WT

TRIAL NO	CYLINDER SPEED	FEED RATE	REPLICATES I	II	III	IV
1	700	100	20.50	21.00	21.00	19.60
2	700	150	21.10	19.50	21.40	19.80
3	700	200	19.00	20.70	21.10	19.50
4	900	100	20.10	22.10	21.10	19.60
5	900	150	20.10	19.70	21.30	21.50
6	900	200	21.00	21.60	20.40	20.90
7	1100	100	20.40	21.10	20.60	21.50
8	1100	150	19.10	22.80	21.80	21.70
9	1100	200	18.50	21.90	21.50	20.10

MOISTURE CONTENT -16%

TRIAL NO	CYLINDER SPEED	FEED RATE	WT REPLICATES I	II	III	IV
1	700	100	19.70	23.00	19.60	19.80
2	700	150	21.00	20.50	18.10	18.80
3	700	200	20.00	19.00	13.60	19.80
4	900	100	21.90	21.00	19.80	20.90
5	900	150	21.50	20.40	19.60	20.20
6	900	200	20.70	21.10	19.20	19.20
7	1100	100	20.60	21.90	19.80	21.80
8	1100	150	21.40	20.90	20.00	21.30
9	1100	200	19.70	26.50	19.90	21.10

MOISTURE CONTENT -18%

TRIAL NO	CYLINDER SPEED	FEED RATE	WT REPLICATES I	II	III	IV
1	700	100	19.40	17.00	13.10	19.70
2	700	150	18.80	19.40	19.90	19.00
3	700	200	17.60	17.90	17.30	16.40
4	900	100	20.40	20.20	18.30	20.70
5	900	150	19.20	18.60	17.80	19.70
6	900	200	20.30	17.40	18.00	18.40
7	1100	100	20.90	20.00	20.10	17.40
8	1100	150	19.90	21.80	18.30	19.90
9	1100	200	20.10	18.50	19.10	18.70

MOISTURE CONTENT -20%

TRIAL NO	CYLINDER SPEED	FEED RATE	WT REPLICATES I	II	III	IV
1	700	100	18.00	18.80	18.20	19.60
2	700	150	18.10	16.60	18.60	21.00
3	700	200	17.30	17.00	18.00	17.30
4	900	100	20.00	17.70	19.30	19.60
5	900	150	19.50	18.00	18.30	19.90
6	900	200	18.60	19.20	18.40	18.90
7	1100	100	19.10	18.20	19.00	16.80
8	1100	150	15.60	19.70	18.20	19.60
9	1100	200	18.00	18.90	19.70	18.90

APPENDIX 7 MECHANICAL DAMAGE (YD) - %

MOISTURE CONTENT -12% YD

TRIAL NO	CYLINDER SPEED	FEED RATE	REPLICATES I	II	III	IV
1	700	100	0.80	1.00	0.90	1.25
2	700	150	1.10	1.00	1.00	1.27
3	700	200	0.90	0.85	0.88	0.76
4	900	100	1.50	1.65	1.70	3.00
5	900	150	3.00	1.48	3.27	1.44
6	900	200	1.74	1.69	1.73	1.55
7	1100	100	4.50	4.42	4.67	3.93
8	1100	150	2.15	2.20	2.17	3.20
9	1100	200	2.95	3.00	3.10	3.50

MOISTURE CONTENT -14% YD

TRIAL NO	CYLINDER SPEED	FEED RATE	REPLICATES I	II	III	IV
1	700	100	0.56	0.55	0.30	0.63
2	700	150	1.35	1.20	1.36	0.85
3	700	200	0.71	0.71	0.35	0.56
4	900	100	0.95	1.00	1.00	1.10
5	900	150	1.60	1.52	0.63	0.58
6	900	200	1.15	1.00	0.60	1.23
7	1100	100	1.46	3.35	2.26	2.29
8	1100	150	1.74	1.70	1.72	1.75
9	1100	200	1.76	1.80	1.90	1.82

MOISTURE CONTENT -16%

TRIAL NO	CYLINDER SPEED	FEED RATE	YD REPLICATES I	II	III	IV
1	700	100	0.47	0.62	0.58	1.00
2	700	150	0.20	1.45	1.50	0.70
3	700	200	0.53	0.55	0.63	1.30
4	900	100	2.00	0.45	2.15	0.64
5	900	150	2.20	2.13	0.70	1.15
6	900	200	0.44	0.53	1.08	0.82
7	1100	100	0.80	1.15	1.26	1.17
8	1100	150	1.00	1.15	1.10	1.00
9	1100	200	1.10	1.35	0.65	1.05

MOISTURE CONTENT -18%

TRIAL NO	CYLINDER SPEED	FEED RATE	YD REPLICATES I	II	III	IV
1	700	100	0.85	0.80	0.90	1.08
2	700	150	0.75	0.72	0.61	1.00
3	700	200	0.62	2.63	0.68	1.00
4	900	100	1.40	0.70	0.65	1.33
5	900	150	0.57	2.48	0.45	0.75
6	900	200	0.80	2.52	2.42	2.35
7	1100	100	1.12	2.18	1.66	3.39
8	1100	150	1.01	1.13	2.75	2.65
9	1100	200	1.04	2.38	2.40	2.80

MOISTURE CONTENT -20%

TRIAL NO	CYLINDER SPEED	FEED RATE	YD REPLICATES I	II	III	IV
1	700	100	0.43	0.38	0.30	0.22
2	~~700~~	150	0.86	0.30	0.53	0.48
3	700	200	0.69	0.66	0.39	0.40
4	~~900~~	100	0.52	0.48	0.51	0.53
5	900	150	0.25	0.25	0.29	0.30
6	900	200	0.68	0.53	0.41	0.43
7	1100	100	0.77	0.75	0.76	0.75
8	1100	150	0.67	0.70	0.76	0.79
9	1100	200	0.90	0.90	0.56	0.65

APPENDIX 8 THRESHABILITY VALUES (YT) - %

MOISTURE CONTENT -12%

TRIAL NO	CYLINDER SPEED	FEED RATE	YT REPLICATES I	II	III	IV
1	700	100	89.36	88.91	92.15	93.49
2	700	150	90.20	89.83	94.69	90.14
3	700	200	92.80	88.28	90.73	91.12
4	900	100	92.56	92.85	94.45	93.76
5	900	150	92.88	94.12	94.01	93.85
6	900	200	93.24	93.24	95.14	93.93
7	1100	100	96.25	94.56	94.56	96.77
8	1100	150	94.72	94.44	96.49	94.24
9	1100	200	94.83	94.76	94.22	96.26

MOISTURE CONTENT -14%

TRIAL NO	CYLINDER SPEED	FEED RATE	YT REPLICATES I	II	III	IV
1	700	100	91.96	85.74	88.10	89.66
2	700	150	89.85	90.03	88.34	89.72
3	700	200	90.03	89.12	90.07	92.33
4	900	100	91.32	92.69	93.10	92.57
5	900	150	91.81	96.45	93.43	90.42
6	900	200	92.63	92.71	92.65	95.80
7	1100	100	94.14	93.84	96.61	93.50
8	1100	150	97.39	95.33	95.43	94.63
9	1100	200	97.73	95.71	95.26	93.95

MOISTURE CONTENT -16%

YT

TRIAL NO	CYLINDER SPEED	FEED RATE	REPLICATES I	II	III	IV
1	700	100	87.13	92.35	89.41	92.31
2	700	150	88.51	89.05	86.20	87.57
3	700	200	87.46	86.36	86.34	88.78
4	900	100	92.36	91.83	87.54	92.54
5	900	150	94.84	92.21	91.15	88.32
6	900	200	93.16	93.47	92.63	92.71
7	1100	100	94.76	93.62	95.87	96.03
8	1100	150	94.79	94.66	95.26	95.55
9	1100	200	87.02	92.39	94.48	94.86

MOISTURE CONTENT -18%

YT

TRIAL NO	CYLINDER SPEED	FEED RATE	REPLICATES I	II	III	IV
1	700	100	92.71	90.25	88.02	90.88
2	700	150	92.02	88.64	90.77	89.79
3	700	200	84.09	89.96	89.33	93.01
4	900	100	90.91	93.33	93.24	93.24
5	900	150	94.59	94.11	93.01	93.05
6	900	200	91.63	93.01	86.86	95.12
7	1100	100	91.11	94.01	95.18	94.74
8	1100	150	96.39	93.95	92.11	92.34
9	1100	200	95.97	90.81	93.01	92.79

MOISTURE CONTENT -20%

YT

TRIAL NO	CYLINDER SPEED	FEED RATE	REPLICATES I	II	III	IV
1	700	100	86.70	86.38	86.49	87.40
2	700	150	88.50	94.00	86.01	86.87
3	700	200	88.21	84.04	86.55	83.94
4	900	100	91.41	89.76	91.99	91.19
5	900	150	91.29	93.75	89.00	90.94
6	900	200	93.45	91.47	90.17	90.57
7	1100	100	92.15	94.51	94.06	91.97
8	1100	150	94.36	94.32	90.53	92.77
9	1100	200	91.67	92.93	93.67	94.25

APPENDIX 9 TOTAL WASTAGE (YTW) - LBS

MOISTURE CONTENT -12%

TRIAL NO	CYLINDER SPEED	FEED RATE	YTW REPLICATES I	II	III	IV
1	700	100	2.29	2.41	1.81	1.44
2	700	150	2.09	2.18	1.30	2.14
3	700	200	1.51	2.42	1.85	1.95
4	900	100	1.80	1.82	1.51	1.93
5	900	150	1.95	1.45	1.89	1.54
6	900	200	1.75	1.73	1.23	1.51
7	1100	100	1.62	1.89	1.94	1.46
8	1100	150	1.52	1.58	1.15	1.83
9	1100	200	1.70	1.77	1.78	1.46

MOISTURE CONTENT -14%

TRIAL NO	CYLINDER SPEED	FEED RATE	YTW REPLICATES I	II	III	IV
1	700	100	1.76	3.10	2.56	2.14
2	700	150	2.41	2.16	2.76	2.19
3	700	200	2.02	2.39	2.17	1.60
4	900	100	1.92	1.83	1.66	1.66
5	900	150	1.95	0.99	1.53	2.17
6	900	200	1.77	1.78	1.61	1.13
7	1100	100	1.48	1.96	1.15	1.86
8	1100	150	0.82	1.44	1.36	1.53
9	1100	200	0.74	1.32	1.41	1.56

MOISTURE CONTENT -16% YTW

TRIAL NO	CYLINDER SPEED	FEED RATE	REPLICATES I	II	III	IV
1	700	100	2.62	1.89	2.18	1.71
2	700	150	2.46	2.52	2.73	2.46
3	700	200	2.60	2.69	1.93	2.46
4	900	100	2.09	1.81	2.84	1.68
5	900	150	1.56	1.99	1.87	2.57
6	900	200	1.51	1.48	1.61	1.55
7	1100	100	1.24	1.64	1.06	1.12
8	1100	150	1.32	1.35	1.16	1.15
9	1100	200	2.75	2.35	1.22	1.30

MOISTURE CONTENT -18% YTW

TRIAL NO	CYLINDER SPEED	FEED RATE	REPLICATES I	II	III	IV
1	700	100	1.57	1.78	1.67	1.99
2	700	150	1.63	2.33	1.95	2.12
3	700	200	2.89	2.22	1.96	1.30
4	900	100	2.12	1.48	1.35	1.66
5	900	150	1.14	1.54	1.32	1.51
6	900	200	1.85	1.63	2.75	1.31
7	1100	100	2.07	1.61	1.29	1.48
8	1100	150	0.91	1.55	1.92	2.02
9	1100	200	1.01	2.10	1.77	1.84

MOISTURE CONTENT -20% YTW

TRIAL NO	CYLINDER SPEED	FEED RATE	REPLICATES I	II	III	IV
1	700	100	2.47	2.63	2.51	2.52
2	700	150	2.23	1.05	2.70	2.85
3	700	200	2.15	2.81	2.49	2.85
4	900	100	1.82	1.90	1.64	1.82
5	900	150	1.74	1.17	2.07	1.86
6	900	200	1.34	1.73	1.88	1.86
7	1100	100	1.64	1.13	1.27	1.47
8	1100	150	0.98	1.25	1.86	1.56
9	1100	200	1.65	1.50	1.35	1.21

APPENDIX 10 : STRAW:GRAIN RATIO (S:G)

MOISTURE CONTENT -12%

TRIAL NO	CYLINDER SPEED	FEED RATE	S:G REPLICATES I	II	III	IV
1	700	100	1.47	1.49	1.39	1.67
2	700	150	1.58	1.54	1.41	1.57
3	700	200	1.66	1.58	1.73	1.45
4	900	100	1.45	1.38	1.37	1.34
5	900	150	1.54	1.51	1.40	1.44
6	900	200	1.40	1.41	1.64	1.49
7	1100	100	1.50	1.54	1.54	1.41
8	1100	150	1.40	1.42	1.44	1.40
9	1100	200	1.35	1.28	1.45	1.43

MOISTURE CONTENT -14%

TRIAL NO	CYLINDER SPEED	FEED RATE	S:G REPLICATES I	II	III	IV
1	700	100	1.44	1.38	1.38	1.55
2	700	150	1.36	1.56	1.33	1.52
3	700	200	1.62	1.41	1.36	1.56
4	900	100	1.48	1.26	1.36	1.54
5	900	150	1.48	1.54	1.35	1.32
6	900	200	1.38	1.31	1.45	1.39
7	1100	100	1.44	1.37	1.42	1.32
8	1100	150	1.61	1.18	1.28	1.29
9	1100	200	1.70	1.28	1.32	1.48

MOISTURE CONTENT -16% S:G

TRIAL NO	CYLINDER SPEED	FEED RATE	REPLICATES I	II	III	IV
1	700	100	1.53	1.17	1.54	1.51
2	700	150	1.37	1.43	1.76	1.66
3	700	200	1.50	1.62	2.67	1.51
4	900	100	1.27	1.38	1.52	1.39
5	900	150	1.32	1.45	1.54	1.47
6	900	200	1.41	1.36	1.60	1.60
7	1100	100	1.42	1.28	1.52	1.28
8	1100	150	1.33	1.38	1.49	1.34
9	1100	200	1.53	0.88	1.51	1.36

MOISTURE CONTENT -18% S:G

TRIAL NO	CYLINDER SPEED	FEED RATE	REPLICATES I	II	III	IV
1	700	100	1.57	1.94	2.81	1.53
2	700	150	1.66	1.57	1.51	1.62
3	700	200	1.84	1.79	1.88	2.04
4	900	100	1.44	1.47	1.73	1.41
5	900	150	1.60	1.68	1.79	1.54
6	900	200	1.46	1.86	1.77	1.71
7	1100	100	1.39	1.50	1.49	1.86
8	1100	150	1.51	1.29	1.72	1.50
9	1100	200	1.49	1.70	1.61	1.67

MOISTURE CONTENT -20% S:G

TRIAL NO	CYLINDER SPEED	FEED RATE	REPLICATES I	II	III	IV
1	700	100	1.77	1.65	1.75	1.54
2	700	150	1.75	2.00	1.68	1.38
3	700	200	1.89	1.93	1.77	1.88
4	900	100	1.50	1.81	1.58	1.55
5	900	150	1.56	1.77	1.72	1.50
6	900	200	1.68	1.60	1.72	1.63
7	1100	100	1.61	1.74	1.63	1.97
8	1100	150	2.20	1.53	1.74	1.55
9	1100	200	1.78	1.64	1.53	1.64