GRAIN COMBINE LOSS CHARACTERISTICS

Thesis for the Degree of M. S.
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Erling Orvald Nyborg
1967

THESIS

ABSTRACT

GRAIN COMBINE LOSS CHARACTERISTICS

by Erling Orvald Nyborg

A digital computer program was written to analyze grain combine loss data. The program compared the goodness-of-fit of three simple correlation models (expressing loss as a function of feedrate) and of two multiple correlation models (expressing loss as a function of feedrate and grain/straw ratio).

The use of feedrate (weight per minute of straw and chaff) and of throughput (weight per minute of grain, straw and chaff) as independent variables was examined by comparing fits of the correlation models.

The effect of yearly climatic variation on crop variables was examined in order to determine the validity of comparing loss data from machines tested in different years and crop conditions.

Analysis of loss data from nine combines, each tested in five crop conditions, and from one combine tested in twenty crop conditions, over a four year period, indicated the following:

(1) A multiplicative model, percent loss = a $(\text{feedrate})^b$ $(\text{grain/straw})^c$, described rack, shoe and cylinder performance in fields of varying grain and straw yield. In uniform fields, more simplified models best described performance.

(2) The use of "feedrate" as an independent variable accounted for more of the variation in grain loss than did the

use of "throughput", when grain/straw variation was neglected. When grain/straw variation was considered, both variables described the process equally well.

(3) Unless some measure is made of crop physical properties (perhaps straw break-up and ease-of threshing) comparison of loss tests, conducted in different crop conditions and growing seasons, is not valid. A standard combine can, however, be used to make valid comparisons.

Approved H. F. McColly
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GRAIN COMBINE LOSS CHARACTERISTICS

By

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A THESIS

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TERMINOLOGY

Name		Meaning
Cylinder loss	-	unthreshed grain in the rack effluent and shoe effluent
Exponential model	-	percent loss = a (feedrate)^{b}
Feedrate	-	the rate (pounds per minute) of straw and chaff passing through a combine
Grain/Straw ratio	-	the weight ratio of grain yield to straw yield
Multiple linear model	-	percent loss = a + b (feedrate) + c (grain/straw)
Multiplicative model	-	percent loss = a (feedrate)^{b} (grain/straw)^{c}
Percent loss	-	$\frac{\text{weight loss}}{\text{weight total grain}} \times 100$
Rack loss	-	free (threshed) grain in the straw rack effluent
Residual	-	the difference, $(Y-\hat{Y})$, between an experimentally determined value for Y and a predicted value for Y
Shoe loss	-	free (threshed) grain in the shoe effluent
Simple exponential model	-	percent loss = a (b)^{feedrate}
Simple linear model	-	percent loss = a + b (feedrate)
Tailings	-	material which falls through the chaffer but passes over the sieve and is returned to the cylinder for re-threshing
Throughput	-	the rate (pounds per minute) of straw, chaff and grain passing through a combine
Whitecap	-	an unthreshed spikelet of wheat in the combine grain tank

LIST OF SYMBOLS

Symbol		Meaning
a	-	y-intercept of fitted regression line
$\pm A$	-	confidence interval for prediction of Y, given an X
b	-	slope of fitted regression line
C	-	coefficient of determination $100(r^2)\%$
CL	-	cylinder loss, percent of yield
E(Y)	-	expected value of Y
$F_{calc.}$	-	"F-distribution" statistic, calculated value
$F_{tab.}$	-	"F-distribution" statistic, from F-table
FR	-	feedrate, pounds per minute
G/S	-	grain to straw ratio
Ho	-	null hypothesis
RL	-	rack loss, percent of yield
r_{yx_1}	-	simple correlation coefficient, loss on feedrate
r_{yx_2}	-	simple correlation coefficient, loss on grain/straw
$r_{x_1x_2}$	-	simple correlation coefficient, feedrate on grain/straw
$r_{yx_1 \cdot x_2}$	-	partial correlation coefficient, loss on feedrate with grain/straw held constant
$r_{yx_2 \cdot x_1}$	-	partial correlation coefficient, loss on grain/straw with feedrate held constant

R	-	multiple correlation coefficient
S. E. y	-	standard error of the estimate of Y
SL	-	shoe loss, percent of yield
S_x	-	standard deviation of X
S_y	-	standard deviation of Y
S_{xy}	-	covariance (X, Y)
S_{y^2}	-	variance of Y
t	-	"t-distribution" statistic
TH	-	throughput, pounds per minute
$\overline{X}$	-	the mean of the X-measures
$\overline{Y}$	-	the mean of the Y-measures
$\hat{Y}$	-	the predicted value of Y
α	-	y-intercept of true regression line
β	-	slope of true regression line
ϵ	-	error term in fitted regression equation
Σ	-	summation
Σ_{x^2}	=	$\Sigma(X-\overline{X})^2 = \Sigma X^2 - (\Sigma X)^2/n$
Σ_{y^2}	=	$\Sigma(Y-\overline{Y})^2 = \Sigma Y^2 - (\Sigma Y)^2/n$
Σ_{xy}	=	$\Sigma XY - (\Sigma X \Sigma Y)/n$

INTRODUCTION

Basis for the Problem

Evaluating the performance of a grain combine in a specific crop condition is complicated both by machine and crop variables. This makes comparison of performance of one machine in two crop conditions difficult. It also makes performance comparison of two different machines in differing crop conditions impossible unless the effect of crop variables is understood.

At present, there is much difference of opinion in how to evaluate combine performance. A logical approach to this problem would be of value both to manufacturer test departments and public test agencies.

Literature Review

Examination of combine test reports from seven different public test agencies (1),* and from several private test departments, indicates that there is much difference of opinion in how to rate combine performance. Grain loss is expressed in several different ways (percent of yield, bushels per acre, pounds per minute) and work rate is also expressed in several different ways (pounds per minute of straw and chaff, pounds per minute of straw, grain and chaff, pounds per minute of grain, miles per hour, acres per hour).

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*Numbers in parenthesis refer to publications listed in "References".

In most instances, no attempt has been made to compare performance of combines tested in different test seasons. A "standard" comparison machine has been used at at least two of the public agencies (7), but reports on comparison to a standard are available from only one agency.

Considerable work has been done regarding the effect of crop and machine variables on threshing performance (2, 12) and separation performance (5, 6, 8, 9, 11) but results of such studies have not been fully incorporated into combine test programs.

In most instance, the approach has been to assume constant crop conditions in a test field and to simply express loss as a function of combine rate of work. Experiences from test work in Saskatchewan (13) indicate that selecting a uniform field for loss tests is nearly impossible. It further indicates that accounting for variation in crop variables, in a test field, is necessary both for determination of combine loss characteristics and for performance comparison of machines.

Objectives

The objectives of this research are:

(1) To determine the important parameters affecting combine loss characteristics.

(2) To determine mathematical models which describe combine performance as a function of machine and crop variables.

(3) To test the goodness of fit of these models by comparing them for several combines in several loss conditions. (Comparison

will be on loss data from nine combines, each tested in five crop conditions and on loss data from one combine tested in twenty different crop conditions over a four year period. This represents a total of 576 individual loss collections.)

(4) To arrive at a method for comparing performance of two different machines on the basis of loss tests conducted in dissimilar crop conditions.

(5) To write a digital computer program to analyze combine loss data, determining the best-fit regression equation.

DATA COLLECTION

Field and Crop Conditions

The data was collected in Saskatchewan during the 1961 to 1964 harvests, by the former Saskatchewan Agricultural Machinery Administration. The selected crops represent typical field conditions occurring in the province. Test sites were selected on a basis of uniformity (level terrain, relatively weed free, uniform straw length, uniform maturity).

All loss tests were conducted in windrowed fields. This served two purposes: It eliminated extreme variation in grain and straw moisture content and it enabled full loading of the test machines in light crops.

Loss tests were conducted at dry grain moisture contents (spring wheat - below 14.6%, durum - below 14.9%, barley - below 14.9%, oats - below 14.1%).

Collection Technique

As outlined in (13), a batch collector (Figure 1), constructed so that it could be quickly coupled to any test combine, was used for collection of the rack effluent, shoe effluent and grain.

Operation of the batch collector is as follows: A small engine (Figure 2) drives two adjustable conveyors, one positioned beneath the straw walkers and one beneath the shoe. When the combine reaches a stable operating condition, the bag mechanism is tripped, activating the grain tank solenoid (Figure 3), starting the distance counter (Figure 4) and activating a warning signal (light or buzzer) for the combine operator. Upon receipt of the signal, the combine operator starts a stop-watch. When the bags are full, the procedure is reversed.

Collected samples were immediately weighed (Figure 5).

Ten such collections, at ten different ground speeds, were made in each test field for each test combine and a "standard" combine. This was a test series.

The Use of a Standard Machine

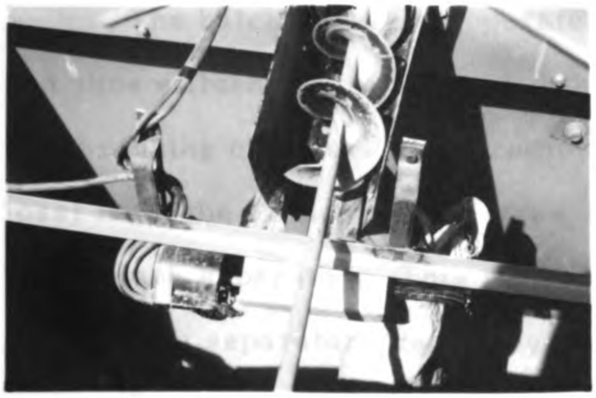
As noted above, in each test series, loss data was collected for both the test combine and the "standard" combine. The value of a standard is explained as follows: In each test series, loss characteristics of the standard combine are compared to those of the test machines. This allows indirect comparison of combines tested in different years and crop conditions. For example, in a 1961 wheat field, the capacity of machine A was 2 times the capacity of the standard combine at a certain loss level, while in a 1963 wheat field, the capacity of machine B was 1.5 times that of the standard combine. This allows us to say that the capacity of machine A in wheat is roughly 1.3 times that of machine B, at a certain loss level. Without the use of a standard, or without a method of assessing the importance of crop variables, this sort of comparison would be meaningless. Combine loss characteristics are very dependent upon crop growing conditions in a specific year.

Batch Collector

Figure 1

Batch Collector Drive

Figure 2



Grain Tank Solenoid

Figure 3

Distance Counter

Figure 4

Time of Collection

Since crop conditions may change quickly during the day, loss collections were usually conducted in mid-afternoon when conditions were relatively stable. Loss collections for the group of test machines were collected in as short a period of time as possible, to reduce the effect of change in moisture content (collection of ten samples for one machine took approximately twenty minutes).

Sample Processing

Rough scalping of the samples was done with a batch separator (Figure 6), a modified small pull-type combine.

The batch separator operates as follows: The rack effluent and shoe effluent are first passed through the separator, by-passing the threshing cylinder. This removes free grain (rack loss and shoe loss) from the effluent. The straw and chaff is collected as it passes through the separator. This material is passed through the cylinder of the batch separator, removing unthreshed grain (cylinder loss).

Final cleaning of the samples was done on a fanning mill (Figure 7).

Weighing a Sample

Figure 5

Processing in Batch Separator

Figure 6

Final Cleaning

Figure 7

PARAMETERS AFFECTING COMBINE PERFORMANCE

Purpose of Loss Tests

Loss tests are a method of determining the performance characteristics of a complete machine. They are not an attempt at determining the performance of all the individual components of a combine, such as could be conducted during the intermediate design stages of a machine.

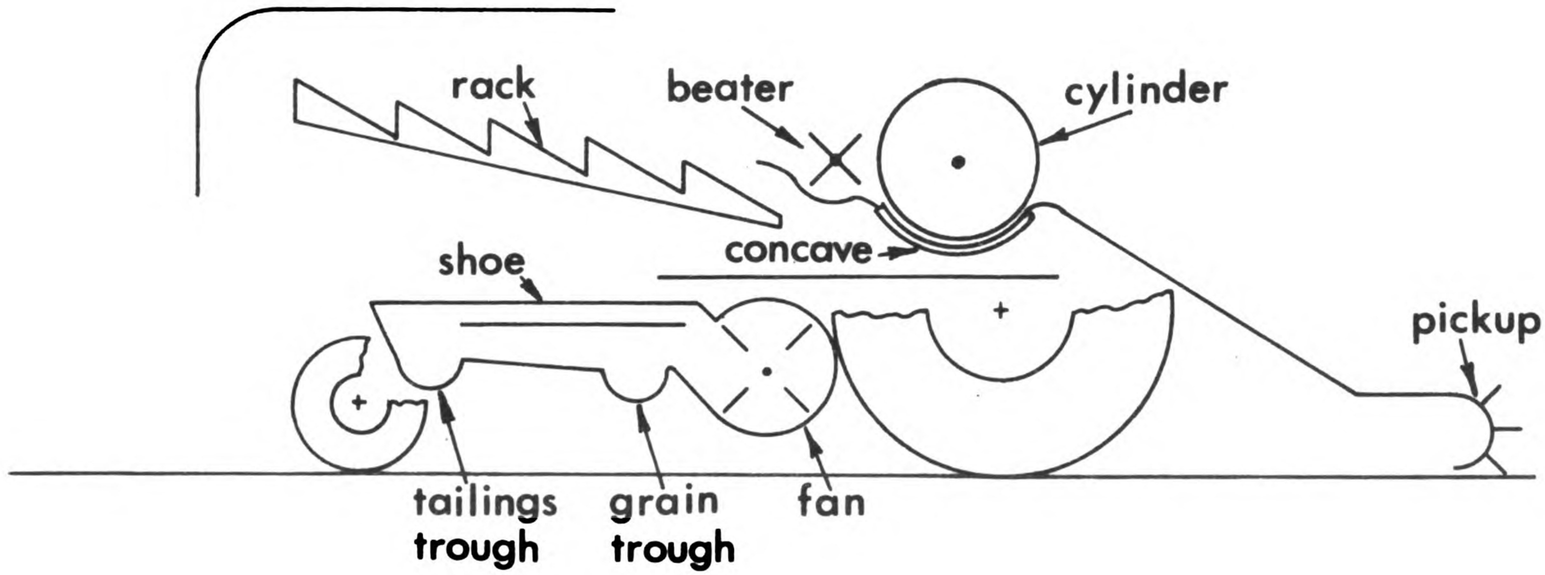
Figure 8 is a schematic cross-sectional view of a grain combine, illustrating the points of importance in combine performance determination. Most of the components shown in Figure 8 are interrelated. The adjustment and performance of one component may affect the performance of several other components.

For purposes of a loss test, it is necessary that the combine be adjusted to an optimum condition. Grain damage, straw break-up, cylinder loss, rack loss, shoe loss and free grain in the tailings should all be at a minimum. Under-cylinder separation should be maximized and the grain must be acceptable (reasonably free of chaff and whitecaps).

Interdependence of Parameters

In order to maximize performance, the interdependence of the parameters (Figure 8) must be understood:

- under-cylinder separation = f_1 (cylinder speed, concave clearance, feedrate, moisture content, crop)



SCHEMATIC CROSS-SECTIONAL VIEW OF A GRAIN COMBINE
FIGURE 8

- cylinder loss = f_2 (cylinder speed, concave clearance, feedrate, moisture content, crop)
- grain damage = f_3 (cylinder speed, concave clearance, feedrate, amount of grain in tailings, moisture content, crop)
- straw damage = f_4 (cylinder speed, concave clearance, moisture content, crop)
- rack loss = f_5 (straw breakup, amount of tailings, feedrate, crop)
- shoe loss = f_6 (straw breakup, feedrate, crop)

Elimination of Variables

The effect of some of the above variables can be minimized as follows:

Moisture content

By windrowing the crop prior to loss collection, the moisture content of the straw and grain stabilizes at a uniform level. This reduces errors due to large variations in moisture content. Conducting all tests on crops that are relatively similar in moisture content (on "dry" grain) improves the validity of comparison between machines tested in different years. Collection of loss data in a short period of time reduces errors due to change in moisture content during collection.

Tailings

Before the test, chaffer, sieve and fan settings must be adjusted to minimize (if possible, eliminate) free grain in the tailings and minimize shoe loss, while maintaining an acceptable sample in the grain tank. These adjustments eliminate further concern about the amount of tailings since the optimum shoe setting, for minimum shoe loss, minimum tailings and an acceptable sample of grain, has been obtained.

Cylinder loss and grain damage

Before testing, an optimum cylinder setting must be obtained. This is the combination of cylinder speed and concave-to-cylinder clearance which minimizes cylinder loss, crackage and straw break-up for a specific crop and crop condition. This adjustment eliminates further concern about the effect of straw break-up on rack and shoe performance and eliminates concern about the amount of under-cylinder separation, since this is the necessary setting to obtain maximum threshing efficiency.

Total Loss

With the simplifications introduced above, it is now apparent that:

- total loss = f_7 (feedrate, crop variables).

The components of total loss are:

total loss = (rack loss + shoe loss + cylinder loss + pickup loss + body loss).

To simplify analysis, body loss and pickup loss can be excluded in analysis of the combine. Body loss is leakage of grain through the body of the machine. It is an indication of quality con

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control during manufacture rather than of combine performance. Although of concern in small seed crops (rapeseed, clover, alfalfa, etc.) it is of little concern in grain and hence need not be considered in loss tests. On the other hand, pickup loss (3, 16) is a function of the type of windrower, stubble height, time of windrowing, pickup adjustment, ground speed, crop yield, straw length, moisture content, weathering, etc. In light crops pickup loss may be the largest component of total loss, whereas in heavy crops it is negligible. Since the pickup mechanism is a machine in itself, it can be evaluated independently from the combine, and need not be considered in loss tests on a combine.

After these simplifications, it is apparent that only rack loss, shoe loss and cylinder loss (dependent variables) and feedrate and crop conditions (independent variables) need be determined in combine loss testing.

Crop Variables

Which crop variables should be measured? Using the simplifications introduced above, for a certain type and variety of crop, of constant grain moisture content and constant straw moisture content, only two crop variables, grain yield and straw yield, remain undescribed. The final result is:

- total loss = f_{10} (rate of work, grain yield, straw yield).

Methods of Expressing Variables

Loss can be expressed in two meaningful ways:

- unit weight of grain loss per unit field area (i. e. bus/acre, kg/ha)
- loss as percent of total grain (i. e. percent of yield).

The second method (percent of yield) is most useful since it allows easy comparison of performance in different crop conditions.

Rate of work can also be expressed in several ways:

- ground speed (i. e. miles/hour, km/hour)
- field rate (i. e. acres/hour, ha/hour)
- feedrate (i. e. lbs/minute of straw and chaff passing through the combine)
- throughput (i. e. lbs/minute of straw, chaff and grain passing through the combine)

The first two (ground speed and field rate) are not good parameters for use in comparison since they do not take into account the actual amount of material passing through the combine. One of the purposes of the following analysis is to decide whether feedrate or throughput is the best parameter describing work rate.

Grain yield and straw yield can also be expressed in several ways:

- grain yield (i. e. lb/min., bus/acre, kg/ha)
- straw yield (i. e. lb/min, tons/acre, kg/hr)
- grain to straw ratio (i. e. weight grain/weight straw)

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The last method (grain/straw ratio) is the most sensible since it avoids confusion with units of measurement and allows direct comparison between different field conditions.

Using the above terminology, the final model for the process is:

- loss (% of yield) = f_{11} (feedrate, grain/straw), or,
- loss (% of yield) = f_{12} (throughput, grain/straw).

MATHEMATICAL MODEL FOR REGRESSION ANALYSIS

Need for a Model

Before regression analysis can be conducted on the collected data, a mathematical model must be determined so that the data can be examined for closeness of fit to the model. The model should explain both what is expected from theory and what is obtained experimentally.

Simple Model, Constant Grain/Straw Ratio

Consider a loss test conducted in an ideal uniform field (a field of constant grain yield and constant straw yield). Since the grain/straw ratio is constant, it will not enter into the analysis. The models for rack loss, shoe loss and cylinder loss may now be constructed as a function of only feedrate (or throughput).

Rack loss model

At low feedrates, separation through the concave is maximum and the mat of material on the straw rack is of minimum thickness, resulting in efficient separation and negligible loss. As feedrate increases, separation at the concave decreases (non-linearly) resulting in more free grain on the rack. As the amount of material on the rack increases, the oscillation of the straw on the upper portion of the rack virtually ceases. (This can be verified by observing straw rack action at various feedrates, in actual operating conditions.) Once a certain feedrate is reached, separation on the rack virtually ceases and a small further increase in feedrate results in an exponential increase in rack loss. Indeed, the loss-versus-feedrate curve probably is asymptotic to some vertical line.

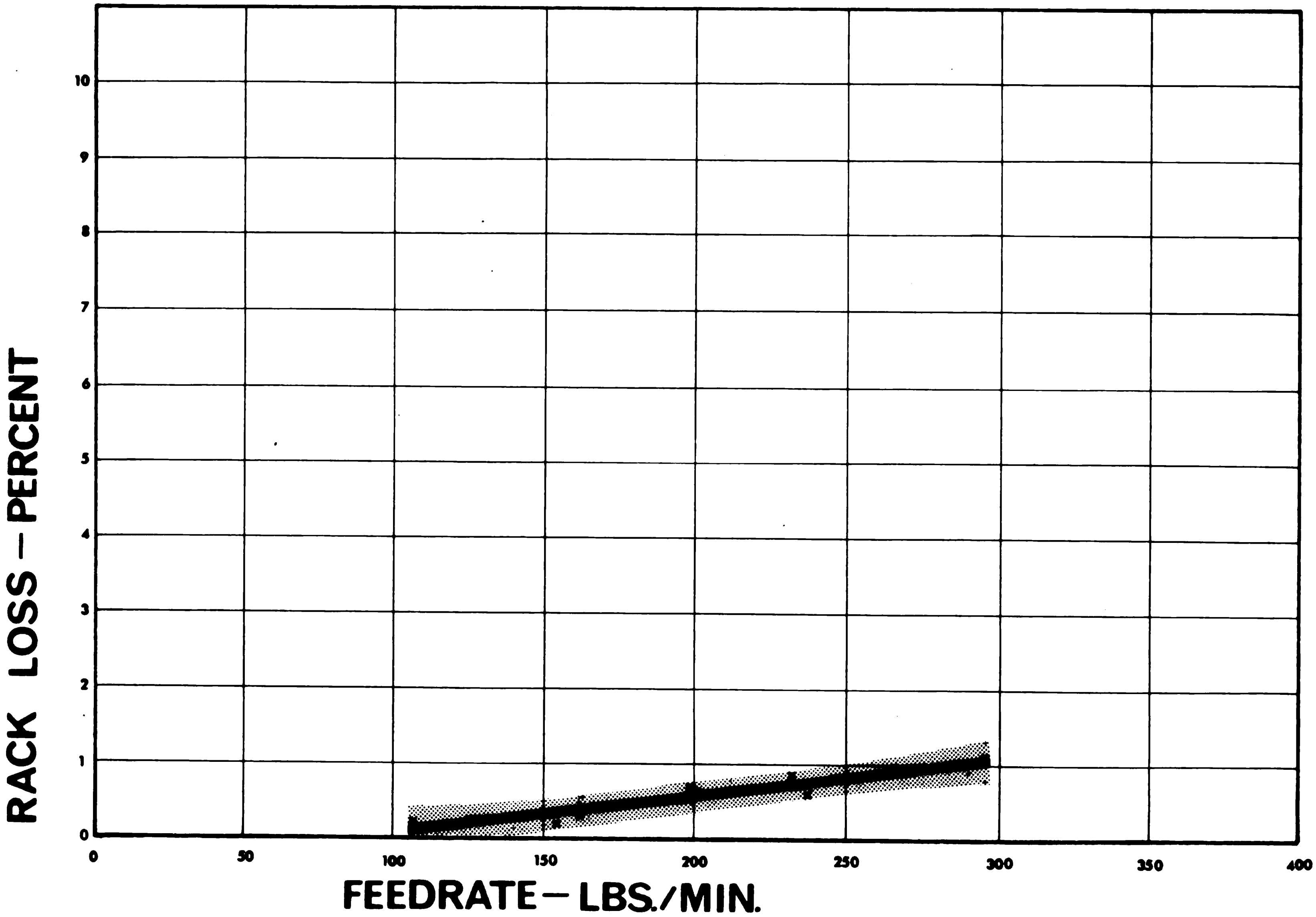
It then appears, that if a loss test is conducted to a sufficiently high feedrate, an exponential model (rack loss = a $(\text{feedrate})^b$) is a reasonable choice. However, if the runs are all at low feedrates, a linear model (rack loss = a + b (feedrate)) or some intermediate model, may be the best fit. To illustrate this point, Figures 9 to 11 show plots of three different sets of loss data. The 90% confidence belts are shown as the shaded area. In Figure 9, in wheat, a linear model, $RL = -6.086 \times 10^{-1} + 5.532 \times 10^{-3}(FR)$, is the best fit. In Figure 10, in barley, an exponential model, $RL = 9.201 \times 10^{-6}(FR)^{2.654}$ is the best fit. In Figure 11, in wheat, a simple exponential model, $RL = 2.587 \times 10^{-1}(1.014)^{FR}$, is the best fit.

Since the best fit model is a function of crop conditions and the range of feedrates achieved, in a series of loss measurements, a regression analysis program should compare all three of the above rack loss models and thus select the best fit.

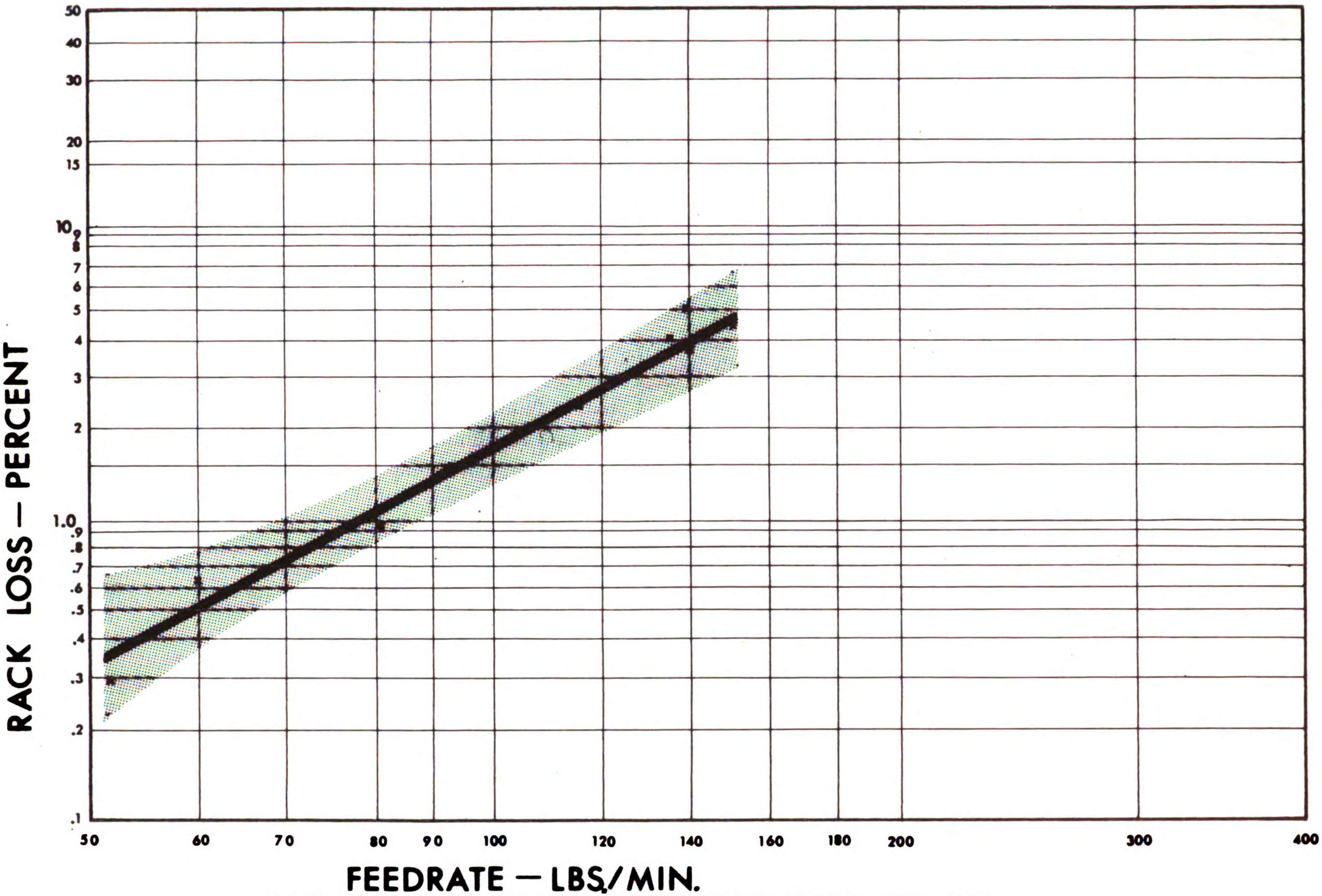
It is also apparent, that for a field of constant grain/straw ratio, both feedrate and throughput will serve equally well as an independent variable in the loss model.

Shoe loss model

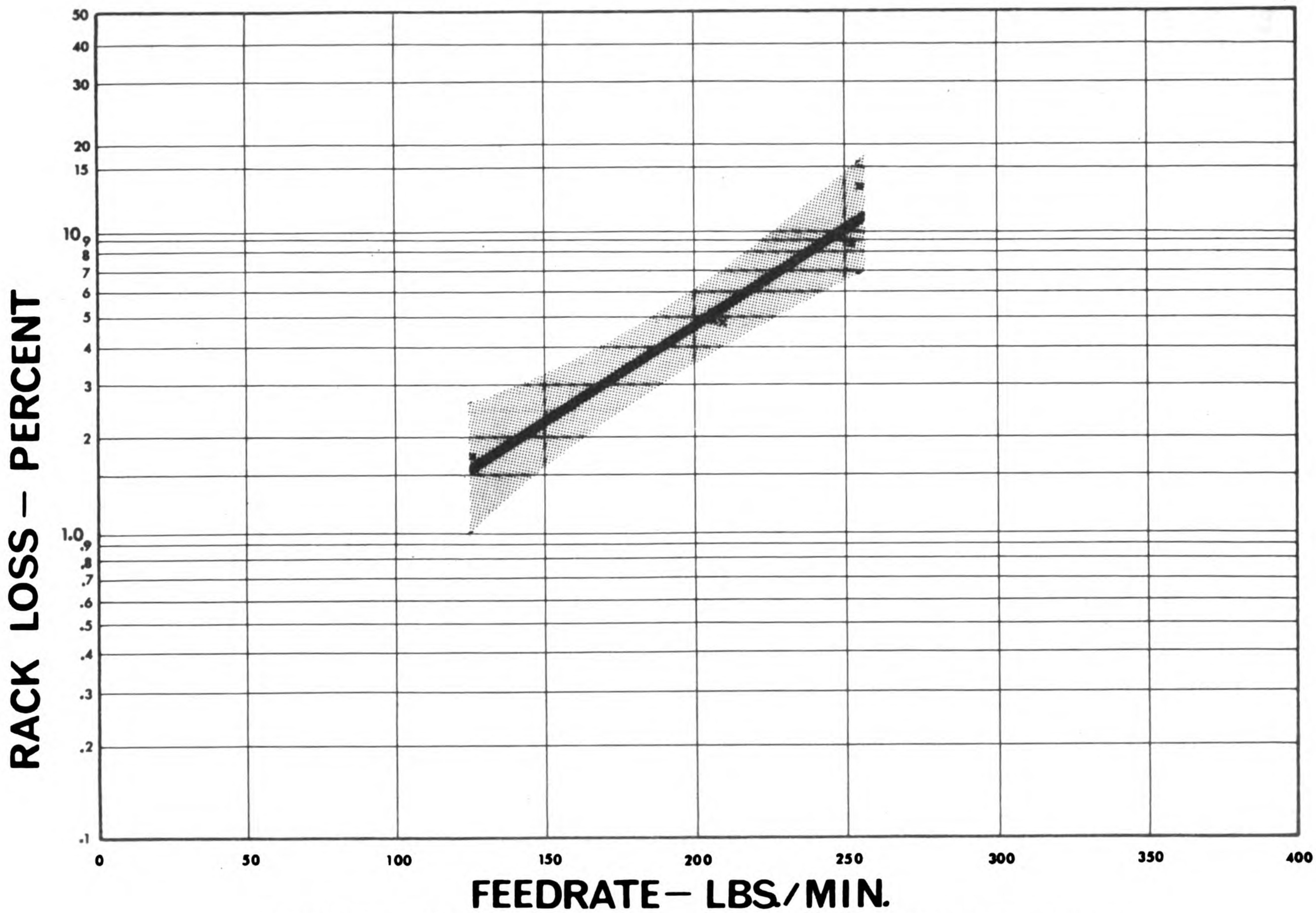
It is expected that, at high feed rates, the layer of grain and chaff on the shoe will become deep enough to cause matting and nearly complete loss of separation ability (this can be verified



RACK LOSS VS. FEEDRATE, LINEAR MODEL BEST FIT
FIGURE 9



RACK LOSS VS. FEEDRATE, EXPONENTIAL MODEL BEST FIT
FIGURE 10



RACK LOSS VS. FEEDRATE, SIMPLE EXPONENTIAL MODEL BEST FIT
FIGURE 11

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by observing shoe action at high feedrates in actual operating conditions). Hence it is to be expected that shoe loss also varies exponentially with feedrate, asymptotically approaching some limit. Since the amount of material passing over the shoe is much less than that passing over the rack and since air, as well as oscillation, is used for separation on the shoe, it is expected that this limit will be reached at higher feedrates than for the rack limit. In most crops, the range of feedrates will probably be low enough, that a linear fit of the data will be a good approximation, however, if much straw break-up occurs an exponential fit may be required. Since the best fit model will again be a function of the range of feedrate and the crop condition, the same three models used for rack loss should also be compared for shoe loss data.

Cylinder loss model

Although cylinder loss increases with feedrate, the increase is usually small in comparison to rack loss and shoe loss. Cylinder loss is a function of cylinder speed. Since only a slight reduction in cylinder speed results in "slugging," it is expected that a linear model will probably best fit the cylinder loss data. However, since a comparison of the three models is to be used for rack loss and shoe loss, some information may be gained by comparing the fits of the three models.

Including Variation in Grain/Straw Ratio

Consider two crops, both having grain yield of X lbs/acre, the first, (a), having a straw yield of Y lbs/acre and the second, (b), having a straw yield of 2Y lbs/acre. For similar ground speeds, the loss will be greater in field (b) than in field (a) since the mat of straw will be twice as thick, hindering separation. It is also expected that for similar feedrates the loss (% of total grain) will be higher in crop (b) than in crop (a). (It is only the amount of straw and chaff, in a mixture of grain, straw and chaff, which hinders separation.) Likewise, it is expected that for similar throughputs, the % loss in field (b) will be greater than that in field (a).

It is then expected, that for a constant feedrate or throughput:

- loss = f_{13} (grain/straw) .

From previous work (13) it has been found that, for a constant feedrate, the relationship between loss and grain to straw ratio is probably exponential:

- loss = $a\ (G/S)^{-b}$

However, since this work was based on a limited amount of data, it would be wise to also test the linear model:

- loss = $a - b\ (G/S)$

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Multiple Model

It is expected, that in fields of varying grain straw ratio, a multiple model, considering the influence of both feedrate and grain/ straw ratio is necessary. Probably a multiplicative model, will describe loss characteristics:

- $\text{loss} = a\,(\text{feedrate})^{b}\,(\text{grain/straw})^{c}$

When the range of feedrate and grain/ straw variation is small, a linear model may be the best fit:

- $\text{loss} = a + b\,(\text{feedrate}) + c\,(\text{grain/straw})$

A program for loss analysis should test the goodness of fit of both the above models, using feedrate as well as throughput for the first independent variable.

DATA ANALYSIS

Technique of Analysis

The first approach used is one of simple correlation (4, 10, 14, 15). Loss is regressed on feedrate or throughput, neglecting any variation in grain/straw ratio. This is the condition that is found in an ideal field (a field of constant grain yield and constant straw yield).

The technique of "multiple regression with two independent variables as a sequence of straight-line regressions" (4) is used to introduce variation in grain/straw ratio, resulting in a multiple correlation model.

Simple Correlation

Transformation of data

The three selected models are such that they can be transformed to the linear case, to facilitate fitting by the method of least squares:

- The linear model, $RL = a + b\,(FR)$, needs no transformation

- The exponential model, $RL = a\,(FR)^{b}$, is transformed by using natural logarithms: $\ln(RL) = \ln(a) + b\ln(FR)$

- The simple exponential model, $RL = a\,(b)^{FR}$, is also transformed using natural logarithms: $\ln(FR) = \ln(a) + FR\ln(b)$.

Fitting now takes place on the transformed data.

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Method of least squares

We are looking for a line of best fit which estimates the true regression line, $\alpha + \beta X$. Let the line of best fit be: $Y = a + bX + \epsilon$, where ϵ is the error term. Let $\epsilon = (-)b\overline{X}$, where $\overline{X} = \sum_{i=1}^{n} X/n$. Then, $Y = a + b(X-\overline{X})$.

Define a residual as $(Y - \hat{Y})$.

The method of least squares requires that:

(1) $\sum_{i=1}^{n} (Y_i - \hat{Y}_i) = 0$

(2) $\sum_{i=1}^{n} (Y_i - \hat{Y}_i)^2 = \text{minimum}$

The first condition can be satisfied as follows:

$$\sum_{i=1}^{n} (Y_i - \hat{Y}_i) = \sum_{i=1}^{n} (Y_i - (a+b(X_i - \overline{X}))) = 0$$

$$= \sum_{i=1}^{n} Y_i - \sum_{i=1}^{n} a - b \sum_{i=1}^{n} (X_i - \overline{X})$$

$$= \sum_{i=1}^{n} Y_i - na = 0$$

Then $a = \sum_{i=1}^{n} Y_i/n = \overline{Y}$, or $\hat{Y} = \overline{Y} + b(X - \overline{X})$.

Satisfying the second condition:

Let $G(a, b) = \sum_{i=1}^{n} (Y_i - a - b(X_i - \overline{X}))^2$

$$\frac{\partial G}{\partial a} = 2 \sum_{i=1}^{n} (Y_i - a - b(X_i - \overline{X}))(-1) = 0$$

Simplifying, $a = \sum_{i=1}^{n} Y_i/n = \overline{Y}$

$$\frac{\partial G}{\partial b} = 2 \sum_{i=1}^{n} (Y_i - a - b(X_i - \overline{X}))(-(X_i - \overline{X})) = 0$$

$$\sum_{i=1}^{n} (Y_i - \overline{Y})(X_i - \overline{X}) - b \sum_{i=1}^{n} (X_i - \overline{X})^2 = 0$$

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Simplifying, $$b = \frac{\sum_{i=1}^{n} ((Y_i - \overline{Y})(X_i - \overline{X}))}{\sum_{i=1}^{n} (X_i - \overline{X})^2}$$

$$b = \frac{\text{covariance } (X, Y)}{\text{variance } (X)}$$

This may be rewritten in the following form to facilitate computation:

$$b = \frac{n \sum_{i=1}^{n} X_i Y_i - \sum_{i=1}^{n} X_i \sum_{i=1}^{n} Y_i}{n \sum_{i=1}^{n} X_i^2 - (\sum_{i=1}^{n} X_1)^2}$$

Checking the Goodness of Fit, Simple Model

Several methods are used to test the three simple correlation models, to ascertain which model is a "best-fit" for the data:

Simple linear correlation coefficient, r_{yx_1}

$$r_{yx_1} = \frac{S_{x_1 y}}{S_{x_1} S_y} , \quad -1 \leq r \leq 1$$

This may be rewritten as; $r_{yx_1} = b \dfrac{S_{x_1}}{S_y}$

In computational form this is: $(r_{yx_1})^2 = (\Sigma_{xy})^2 / \Sigma_{x^2} \Sigma_{y^2}$

Note that the sign of r_{yx_1} is determined by the sign of the sum, (Σ_{xy}), within the brackets, in the numerator.

A high correlation coefficient means that there is a definite relation between X_1 and Y. It can be seen that if the X_1's and Y's are equal in standard deviation, and if the slope, b = 1, then there is a high positive correlation.

Coefficient of determination

$$C = 100(r_{yx_1})^2$$

C is a measure of the percent variation, about the mean, in the data. In other words, C% of the variation in Y is accounted for by X_1.

Standard error of the estimate

$$(S.E._y)^2 = \frac{1}{(n-2)} \sum_{i=1}^{n} (Y_i - \hat{Y}_i)^2 = \frac{(n-1)}{(n-2)} S_{y^2} (1 - r^2_{yx_1})$$

The standard error of the estimate is an index of the amount of scatter, of the measured points, about the calculated regression line. A small value indicates a good fit.

Limits of prediction

The confidence interval for the prediction of Y, given an X_1, may be determined. The limits of prediction are $(Y \pm A)$, where

$$A = t_{\alpha}/2\ (S.E.) \sqrt{1 + 1/n + \left(\frac{(x - \overline{X})^2}{\sum_{i=1}^{n} X_i^2 - n(\overline{X})^2}\right)}$$

where x is a certain X_1 measure for which A is to be calculated.

This results in confidence bands which are the branches of an hyperbola. The confidence level is $(1 - \alpha)$ %.

ANOVA for significance of regression

Let $E(Y_i) = B_o + B_1 X_i$. Test the null hypothesis, $Ho: B_1 = 0$.

Let $F_{calc.} = \frac{\text{mean square due to regression}}{\text{mean square due to residual variation}}$. Compare this to $F_{tab}(1, (n-2), \alpha)$, where $(1 - \alpha)$ is the confidence level. If $F_{calc.} > F_{tab.}$, reject Ho; otherwise do not reject Ho.

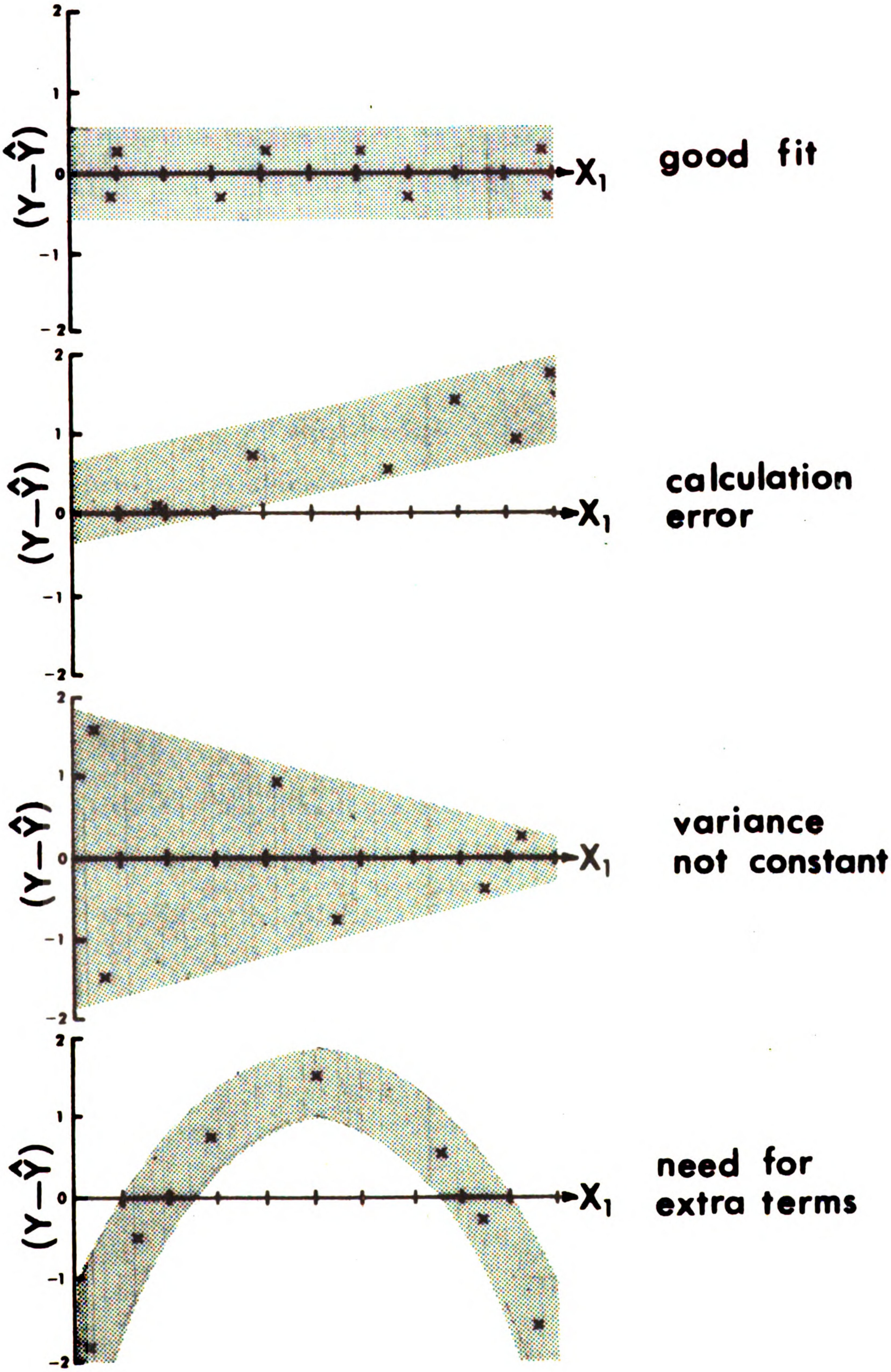
This analysis of variance is explained in Table 1.

Table 1. ANOVA, $Ho: B_1 = 0$

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Total	$(n - 1)$	$\Sigma_y 2$		
Regression	1	$r^2_{yx_1} \Sigma_y 2$	$r^2_{yx_1} \Sigma_y 2 = A$	$F_{calc.} = \frac{A}{B}$
Deviation from Regression (residual variation)	$(n - 2)$	$(1 - r^2_{yx_1}) \Sigma_y 2$	$(1 - r^2_{yx_1}) \frac{\Sigma_y 2}{(n-2)} = B$	

Residual plot

As indicated in (4), the above tests must be used with caution and can give misleading results when comparing models. The plot of residuals, $(Y - \hat{Y})$, against feedrate gives a visual indication of the goodness of fit, when comparing the three models. Figure 12 illustrates some of the information which may be obtained from such a plot.



RESIDUAL PLOTS
FIGURE 12

Expanding the Simple Case into Multiple Correlation

Multiple regression of two independent variables as a sequence of straight line regressions is used in transforming the simple models into multiple models (introducing G/S variation).

Let the desired solution be:

$$Y = a + bX_1 + c X_2$$

Regress Y on X_1. This gives, $Y = a_1 + b_1 X_1$, the result obtained in the previous simple correlation.

Calculate the residuals, $(Y - \hat{Y})$. This was also done in the previous simple correlation.

Regress X_2 on X_1. This gives, $X_2 = a_2 + b_2 X_1$.

Calculate the residuals, $(X_2 - \hat{X}_2)$.

Regress $(Y - \hat{Y})$ on $(X_2 - \hat{X}_2)$. This gives, $(Y - \hat{Y}) = b_3(X_2 - \hat{X}_2)$.

Note that since the sum of the residuals must be zero, this line passes through the origin.

Combine the equations:

$$(Y - (a_1 + b_1 X_1)) = b_3(X_2 - (a_2 + b_2 X_1))$$

$$\hat{Y} = (a_1 - b_3 a_2) + (b_1 - b_3 b_2) X_1 + b_3 X_2$$

$$\hat{Y} = a_4 + b_4 X_1 + b_3 X_2$$

The last equation is the desired multiple regression of Y on (X_1 and X_2).

The above analysis is carried out for the two multiple cases:

(1) the linear model:

$$RL = a + b(FR) + c\ (G/S)$$

(2) the multiplicative model:

$$RL = a(FR)^b \, (G/S)^c$$

which must be transformed to the linear case, with logarithms, before the above analysis can be carried out:

$$\ln RL = \ln a + b \ln (FR) + c \ln (G/S)$$

Two more complicated multiple models could be constructed from the simple correlation models by combining the linear model for Y on X_1 with the exponential model for X_2 on X_1, and by combining the exponential model for Y on X_1 with the linear model for X_2 on X_1. The latter two models were not used in the analysis. Results from the first two models (linear and multiplicative) indicated that the more complicated models were unnecessary.

Checking the Goodness of Fit, Multiple Models

The following methods are used to test the goodness of fit of the multiple correlation models:

Simple correlation coefficients

(1) $$r^2_{yx_1} = (\Sigma_{yx_1})^2 / \Sigma_{y^2} \, \Sigma_{x_1^2}$$

$$r_{yx_1} = \sqrt{r^2_{yx_1}} \;, \quad -1 \leq r_{yx_1} \leq 1$$

This was calculated previously in the simple model analysis.

(2) $$r^2_{yx_2} = (\Sigma_{yx_2})^2 / \Sigma_{y^2} \, \Sigma_{x_2^2}$$

$$r_{yx_2} = \sqrt{r^2_{yx_2}} \;, \quad -1 \leq r_{yx_2} \leq 1$$

$$(3)\quad r^2_{x_1x_2} = (\Sigma_{x_1x_2})^2/\Sigma_{x_1^2}\,\Sigma_{x_2^2}$$

$$r_{x_1x_2} = \sqrt{r^2_{x_1x_2}}\ , \quad -1 \leq r_{x_1x_2} \leq 1$$

The simple correlation coefficients represent the linear correlation between any pair of variables, disregarding the remaining variable. Note that the sign of the simple correlation coefficients is determined by the sign of the sum within the brackets in the numerator.

Partial correlation coefficients

$$(1)\quad r^2_{yx_1\cdot x_2} = (r_{yx_1} - r_{yx_2}r_{x_1x_2})^2/(1 - r^2_{yx_2})(1 - r^2_{x_1x_2})$$

$$r_{yx_1\cdot x_2} = \sqrt{r^2_{yx_1\cdot x_2}}\ , \quad -1 \leq r_{yx_1\cdot x_2} \leq 1$$

$$(2)\quad r^2_{yx_2\cdot x_1} = (r_{yx_2} - r_{yx_1}r_{x_1x_2})^2/(1 - r^2_{yx_1})(1 - r^2_{x_1x_2})$$

$$r_{yx_2\cdot x_1} = \sqrt{r^2_{yx_1\cdot x_2}}\ , \quad -1 \leq r_{yx_2\cdot x_1} \leq 1$$

The partial correlation coefficients represent the relation between two variables, when one or more of the remaining variables is held constant.

Multiple correlation coefficients

$$R^2 = r^2_{y\cdot x_1x_2} = (r^2_{yx_2} + r^2_{yx_1} - 2\, r_{yx_1}\, r_{yx_2}\, r_{x_1x_2})/(1 - r^2_{x_1x_2})$$

$$R = \sqrt{R^2}\ , \quad 0 \leq R \leq 1$$

The above formula shows the relationship between the multiple correlation coefficient and the partial and simple correlation coefficients. Serious truncation errors, resulting in values of $R > 1$, may occur if this formula is used in a computer for computation of R. The following basic definition of R yields correct results when used in a computer:

$$R^2 = \frac{\sum_{i=1}^{n} (\hat{Y}_i - \overline{Y})^2}{\sum_{i=1}^{n} (Y_i - \overline{Y})^2}$$

$$R = \sqrt{R^2} \quad , \quad 0 \leq R \leq 1$$

Note that if $\hat{Y}_i = Y_i$ (i. e., if the prediction is perfect) then $R^2 = 1$. Conversely, if $Y_i = \overline{Y}$ (i.e., $b_1 = b_2 = 0$) then $R^2 = 0$. Thus it can be seen that R^2 is a measure of the usefulness of the terms, other than B_o, in the multiple regression equation, $Y = B_o + B_1X_1 + B_2X_2 + \epsilon$.

Note that R^2 can be made unity simply by using n properly selected coefficients for the model. Hence, some test other than the increase in R^2 must be used to test the significance of the additional term (grain/straw variation) in the equation.

<u>Multiple coefficient of determination</u>

$$C = 100\ R^2 \ .$$

C represents the total percentage of variation in the dependent variable (percent loss) explained by the two independent variables (feedrate and grain/straw variation).

ANOVA for significance of additional regression due to grain/straw

Let $E(Y_i) = B_o + B_1X_{1i} + B_2X_{2i}$.

Test the null hypothesis, $Ho: B_2 = 0$.

$$\text{Let } F_{calc.} = \frac{\text{mean square, additional regression due to } X_2}{\text{mean square, deviation from multiple regression}}$$

Compare this to $F_{tab.}$ $(1, (n-3), \alpha)$, where $(1-\alpha)$ is the confidence level. If $F_{calc.} > F_{tab.}$, reject Ho; otherwise do not reject Ho.

This analysis of variance is explained in Table II. Note that the first part of this table is similar to Table I. This analysis tests the value of the additional term (grain/straw variation).

Standard error of the estimate

$$(S.E._y)^2 = \text{mean square, deviation from multiple regression}$$

$$S.E._y = \sqrt{(1-R^2)\Sigma_y 2/(n-3)}$$

Residual plot

As explained previously, the most important method of determining the necessity of the additional term (grain/straw) in the equation is by examining the improvement in the residual plot, as compared to the residual plot of the simple model.

Interpretation of results

In order to determine the validity of the multiple model as compared to the simple model the following criteria are used:

1. An improvement in the residual plot.
2. The additional regression due to X_2 should be significant.
3. A decrease in the standard error of the estimate.

Table 2. ANOVA, $Ho: B_2 = 0$

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F
Total	(n-1)	Σy^2		
Regression due to X_1	1	$r^2_{yx_1}(\Sigma y^2)$		
Deviation from simple regression	(n-2)	$(1-r^2_{yx_1})\Sigma y^2$		
Additional regression due to X_2	1	$r^2_{yx_2 \cdot x_1}(1-r^2_{yx_1})\Sigma y^2$	$r^2_{yx_2 \cdot x_1}(1-r^2_{yx_1})\Sigma y^2 = J$	$F_{calc} = \frac{J}{K}$
Deviation from multiple regression	(n-3)	$(1-R^2)\Sigma y^2$	$(1-R^2)\frac{\Sigma y^2}{(n-3)} = K$	

4. A noticeable increase in the correlation coefficient (i.e., $R > r_{yx_1}$).
5. At least a 1% increase in the coefficient of determination.

DIGITAL COMPUTER PROGRAM

Description of Analysis Performed by the Program

The FORTRAN loss analysis program, written for the M. S. U. CDC3600 computer is shown in Appendix I.

The Program performs the following functions:

1. Print out of raw data.
2. Calculation and printout of performance parameters and crop variables.
3. Printout of scatter diagrams (rack loss (%) vs. feedrate (lb/min), shoe loss (%) vs. feedrate (lb/min), cylinder loss (%) vs. feedrate (lb/min)).
4. Fitting the loss data to the mathematical models and comparing goodness of fit: The simple linear, exponential and simple exponential models are fitted by the method of least squares. Confidence limits (90% level) are calculated for the three equations. The F statistic (for the significance of regression due to feedrate) is calculated and tested for significance at the 95% level and 97 1/2 % level.

The simple correlation coefficients, r_{yx_1}, coefficients of determination and standard errors of the estimate are calculated. Finally, the graphs of residuals vs. feedrate are printed. This data allows comparison of the three simple models for rack loss, shoe loss and cylinder loss.

The regression of grain straw on feedrate is now conducted for the linear and exponential models. The simple correlation coefficients, $r_{x_1x_2}$, are determined.

The regressions of loss residuals on grain/straw residuals are calculated, using both a linear model and exponential model.

The multiple correlation equations are calculated for both the linear and multiplicative models. The coefficients of simple correlation, r_{yx_2}, and the multiple correlation coefficients, R, are calculated. The standard errors of the estimate are determined and the F statistic (for additional significance of regression due to grain/straw variation) is calculated and tested for significance at the 95% level and 97 1/2% level. The graphs of residuals versus feedrate are printed. This data allows comparison of the two multiple models for rack loss, shoe loss and cylinder loss.

Interpretation of Sample Output

Figures 13 to 16 show output of the computer loss analysis program for a loss test on the standard combine in a non-uniform field of Selkirk wheat. Raw data, crop conditions, intermediate calculations and scatter diagrams are shown in Figure 13; Figures 14 to 16 illustrate the fitting process.

Comparison of the three simple correlation models shows that either the exponential models or simple exponential models are the best fit for rack loss and cylinder loss, while the linear model is the best fit for shoe loss. Examination of Figures 15 and 16 shows a high negative correlation between loss and grain/straw ratio. Comparison of the two multiple models and comparison of the multiple models to the simple models shows that the addition of grain/straw variation significantly improves the fit in all cases. The multiplicative model is the best for rack loss and cylinder loss whereas the linear multiple model is the best fit for shoe loss. Hence, in this example, the best fit equations are:

$$RL = 1.125x10^{-3}\,(FR)^{1.350}\,(G/S)^{-3.177}$$

$$SL = 2.085 - 6.853x10^{-4}(FR) - 1.471\,(G/S)$$

$$CL = 2.961x10^{-3}(FR)^{1.278}\,(G/S)^{-1.529}$$

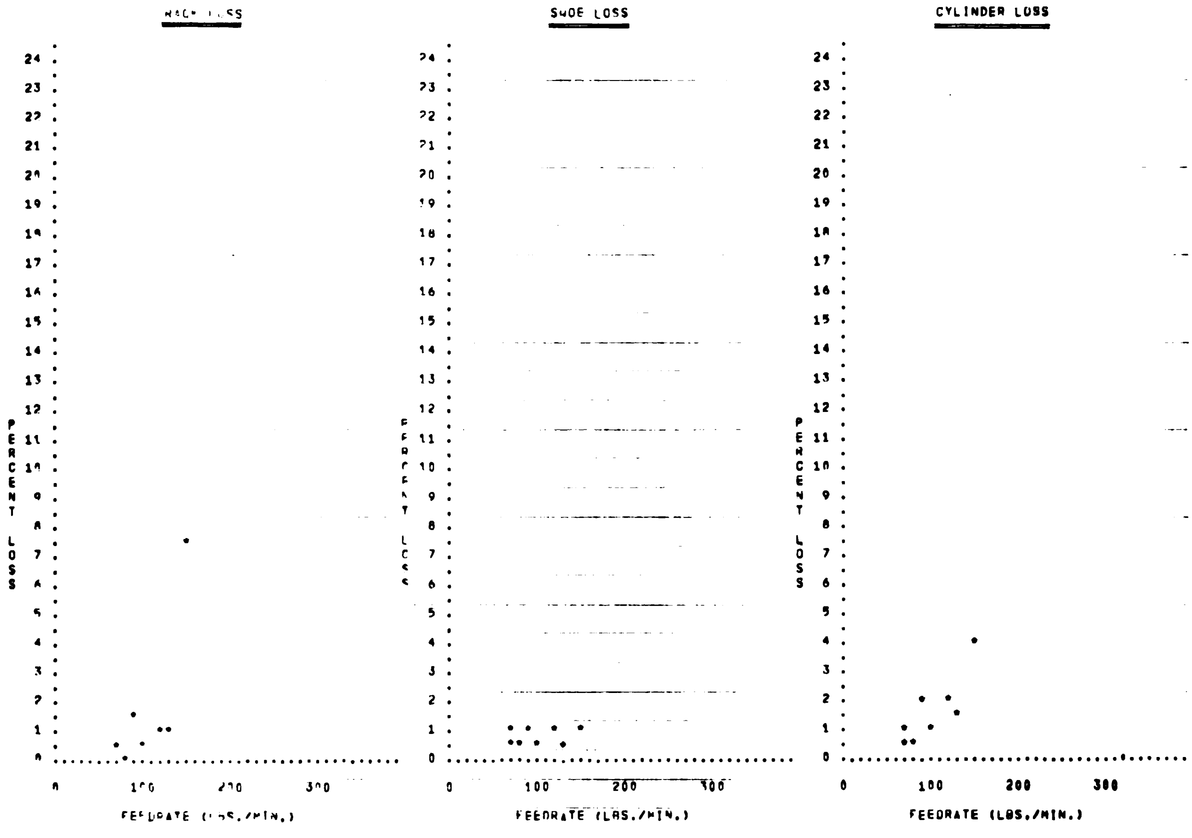
The above example represents data from one combine in one crop condition. These results are not necessarily indicative of what may be expected, as is illustrated in the following discussion of results.

MACHINE	MODEL	TEST NUMBER	SERIES	CROP	VARIETY	WINDROW OR STAND	STRAW	LOCATION	DATE
MF	82	AMS-10	2	WHEAT	SELKIRK	WINDROW	3	ARCOLA	17-8-64

RUN	WIDTH (FEET)	DISTANCE (FEET)	TIME (MINUTES)	STRAW AND LOSS (POUNDS)	CHAFF AND LOSS (POUNDS)	GRAIN COLLECTED (POUNDS)	RACK LOSS (POUNDS)	SHOE LOSS (POUNDS)	CYLINDER LOSS (POUNDS)
1	12.00	73.00	0.49	31.00	4.00	27.00	0.15	0.24	0.21
2	12.00	62.00	0.55	34.00	4.00	36.00	0.17	0.24	0.18
3	12.00	21.00	0.47	30.00	2.00	34.00	0.12	0.15	0.27
4	12.00	56.00	0.39	28.00	4.00	34.00	0.07	0.12	0.25
5	12.00	62.00	0.32	28.00	2.00	19.00	0.29	0.19	0.44
6	12.00	44.00	0.34	30.00	3.00	34.00	0.20	0.17	0.31
7	12.00	55.00	0.25	31.00	2.00	26.00	0.27	0.17	0.35
8	12.00	42.00	0.23	34.00	1.00	18.00	1.50	0.24	0.85
9	12.00	67.00	0.25	29.00	2.00	25.00	0.27	0.21	0.56

RUN	STRAW AND CHAFF (LBS.)	TOTAL GRAIN (LBS.)	FEEDRATE (LBS./MIN.)	RACK LOSS (PERCENT)	SHOE LOSS (PERCENT)	CYLINDER LOSS (PERCENT)	SPEED (MILE/HOUR)	WORK RATE (ACRE/HOUR)	GRAIN YIELD (LBS./ACRE)	GRAIN/STRAW RATIO
1	34.40	27.60	71.47	0.54	0.87	0.76	1.73	2.51	1372.44	0.80
2	37.41	36.59	68.02	0.46	0.66	0.49	1.28	1.86	2142.29	0.98
3	31.46	34.54	66.94	0.35	0.43	0.78	1.23	1.79	2458.44	1.10
4	31.56	34.44	80.72	0.20	0.35	0.73	1.92	2.80	1894.20	1.09
5	29.08	19.92	90.88	1.46	0.95	2.21	2.20	3.20	1166.28	0.69
6	32.32	34.68	98.06	0.58	0.49	0.89	1.47	2.14	2861.10	1.07
7	32.21	26.79	128.84	1.01	0.63	1.31	2.50	3.64	1768.14	0.83
8	34.41	20.59	149.81	7.29	1.17	4.13	2.08	3.02	1779.56	0.60
9	29.96	26.04	119.84	1.04	0.81	2.15	3.05	4.43	1410.82	0.87

MF 82 AMS-10 2 WHEAT SELKIRK WINDROW 3 ARCOLA 17-8-64



RAW DATA, INITIAL CALCULATIONS AND SCATTER DIAGRAMS
FIGURE 13

MF 42 AMS-1A 3 HWEAT SELKIRK WINDROW 3 ARCOLA 17-8-64

FITTING A LINEAR FUNCTION , Y=A+BX

RACK LOSS

PERCENT LOSS=-3.968+000+ 5.578-002(FEED)

FEEDRATE	MEASURED LOSS	CALCULATED LOSS	RESIDUAL
71.67	0.54	0.03	0.513
68.02	0.46	-0.17	0.638
66.94	0.35	-0.23	0.581
80.92	0.20	0.54	-0.343
90.88	1.46	1.10	0.354
95.06	0.58	1.34	-0.758
128.84	1.01	3.22	-2.212
149.61	7.29	4.39	2.907
119.84	1.04	2.72	-1.681

COEFFICIENT OF LINEAR CORRELATION = 0.7397
COEFFICIENT OF DETERMINATION=54.72PERCENT

F(CALC)	F(2.5PCENT)	F(CALC)	F(5PCENT)
8.4595	8.0727	8.4595	5.5914
SIGNIFICANT		SIGNIFICANT	

STANDARD ERROR OF THE ESTIMATE = 1.603

SHOE LOSS

PERCENT LOSS= 2.307-001+ 4.912-003(FEED)

FEEDRATE	MEASURED LOSS	CALCULATED LOSS	RESIDUAL
71.67	0.87	0.58	0.287
68.02	0.66	0.56	0.091
66.94	0.43	0.56	-0.125
80.92	0.35	0.63	-0.280
90.88	0.95	0.68	0.277
95.06	0.49	0.70	-0.207
128.84	0.63	0.86	-0.229
149.61	1.17	0.97	0.200
119.84	0.81	0.82	-0.013

COEFFICIENT OF LINEAR CORRELATION = 0.5461
COEFFICIENT OF DETERMINATION=29.82PERCENT

F(CALC)	F(2.5PCENT)	F(CALC)	F(5PCENT)
2.9749	8.0727	2.9749	5.5914
NOT SIGNIFICANT		NOT SIGNIFICANT	

STANDARD ERROR OF THE ESTIMATE = 0.238

CYLINDER LOSS

PERCENT LOSS=-1.635+000+ 3.231-002(FEED)

FEEDRATE	MEASURED LOSS	CALCULATED LOSS	RESIDUAL
71.67	0.76	0.68	0.081
68.02	0.49	0.56	-0.070
66.94	0.78	0.53	0.254
80.92	0.73	0.98	-0.293
90.88	2.21	1.30	0.908
95.06	0.89	1.44	-0.542
128.84	1.31	2.53	-1.221
149.61	4.13	3.20	0.930
119.84	2.15	2.24	-0.086

COEFFICIENT OF LINEAR CORRELATION = 0.8175
COEFFICIENT OF DETERMINATION=66.82PERCENT

F(CALC)	F(2.5PCENT)	F(CALC)	F(5PCENT)
14.0991	8.0727	14.0991	5.5914
SIGNIFICANT		SIGNIFICANT	

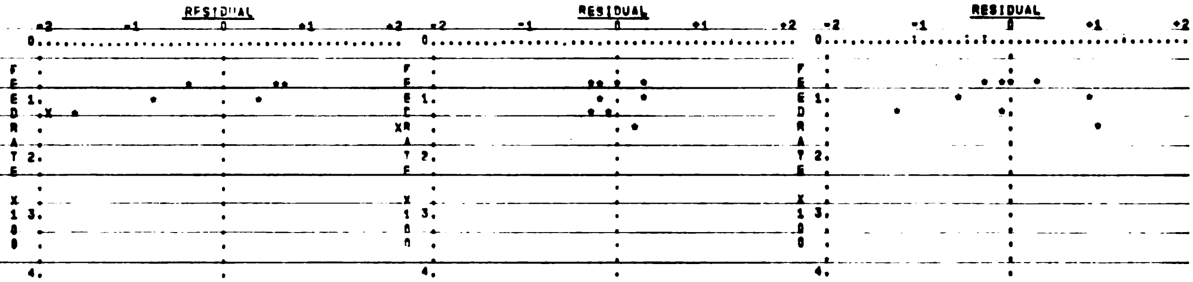
STANDARD ERROR OF THE ESTIMATE = 0.719

LIMITS OF PREDICTION

FEEDRATE	A
71.67	3.33
68.02	3.37
66.94	3.38
80.92	3.25
90.88	3.21
95.06	3.29
128.84	3.41
149.61	3.73
119.84	3.31

FEEDRATE	A
71.67	0.49
68.02	0.50
66.94	0.50
80.02	0.48
90.88	0.48
95.06	0.48
128.84	0.51
149.41	0.55
119.84	0.49

FEEDRATE	A
71.67	1.49
68.02	1.51
66.94	1.52
80.92	1.46
90.88	1.44
95.06	1.44
128.84	1.53
149.61	1.67
119.84	1.48



FITTING AN EXPONENTIAL FUNCTION , Y=A(X)EXP(B)

RACK LOSS

PERCENT LOSS= 2.899-006(FEEDRATE)EXP 2.750

FEEDRATE	MEASURED LOSS	CALCULATED LOSS	RESIDUAL
71.67	0.54	0.38	0.354
68.02	0.46	0.33	0.342
66.94	0.35	0.32	0.095
80.92	0.20	0.53	-0.964
90.88	1.46	0.73	0.604
95.06	0.58	0.83	-0.366
128.84	1.01	1.92	-0.646
149.61	7.29	2.91	0.919
119.84	1.04	1.53	-0.418

COEFFICIENT OF LINEAR CORRELATION = 0.7875
COEFFICIENT OF DETERMINATION=62.01PERCENT

F(CALC)	F(2.5PCENT)	F(CALC)	F(5PCENT)
11.4277	8.0727	11.4277	5.5914
SIGNIFICANT		SIGNIFICANT	

STANDARD ERROR OF THE ESTIMATE = 0.678

SHOE LOSS

PERCENT LOSS= 3.449-002(FEEDRATE)EXP 0.691

FEEDRATE	MEASURED LOSS	CALCULATED LOSS	RESIDUAL
71.67	0.87	0.56	0.445
68.02	0.66	0.54	0.197
66.94	0.43	0.53	-0.205
80.92	0.35	0.60	-0.549
90.88	0.95	0.65	0.383
95.06	0.49	0.67	-0.312
128.84	0.63	0.82	-0.252
149.61	1.17	0.90	0.259
119.84	0.81	0.78	0.035

COEFFICIENT OF LINEAR CORRELATION = 0.4845
COEFFICIENT OF DETERMINATION=23.47PERCENT

F(CALC)	F(2.5PCENT)	F(CALC)	F(5PCENT)
2.1470	8.0727	2.1470	5.5914
NOT SIGNIFICANT		NOT SIGNIFICANT	

STANDARD ERROR OF THE ESTIMATE = 0.369

CYLINDER LOSS

PERCENT LOSS= 1.680-004(FEEDRATE)EXP 1.956

FEEDRATE	MEASURED LOSS	CALCULATED LOSS	RESIDUAL
71.67	0.76	0.71	0.063
68.02	0.49	0.64	-0.271
66.94	0.78	0.62	0.224
80.92	0.73	0.91	-0.221
90.88	2.21	1.14	0.665
95.06	0.89	1.24	-0.320
128.84	1.31	2.25	-0.543
149.61	4.13	3.01	0.315
119.84	2.15	1.95	0.097

COEFFICIENT OF LINEAR CORRELATION = 0.8370
COEFFICIENT OF DETERMINATION=70.06PERCENT

F(CALC)	F(2.5PCENT)	F(CALC)	F(5PCENT)
16.3780	8.0727	16.3780	5.5914
SIGNIFICANT		SIGNIFICANT	

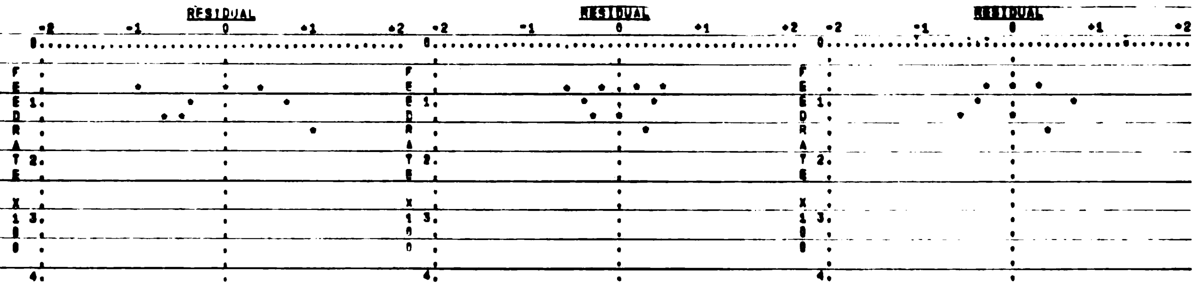
STANDARD ERROR OF THE ESTIMATE = 0.402

LIMITS OF PREDICTION

FEEDRATE	A
71.67	1.41
68.02	1.44
66.94	1.45
80.92	1.37
90.88	1.34
95.06	1.34
128.84	1.45
149.61	1.54
119.84	1.41

FEEDRATE	A
71.67	0.77
68.02	0.78
66.94	0.79
80.02	0.75
90.88	0.74
95.06	0.74
128.84	0.79
149.41	0.84
119.84	0.77

FEEDRATE	A
71.67	0.84
68.02	0.85
66.94	0.86
80.92	0.81
90.88	0.80
95.06	0.80
128.84	0.86
149.61	0.91
119.84	0.83



LINEAR FIT AND EXPONENTIAL FIT
FIGURE 14

MF 82 AMS=10 2 WHEAT SELKIRK WINDROW 3 ARCOLA 17-8-64

FITTING A SIMPLE EXPONENTIAL FUNCTION , Y=A(B)EXP(X)

RACK LOSS

PERC LOSS= 4.975-002(1.029+000)EXP(FEED)

FEEDRATE	MEASURED LOSS	CALCULATED LOSS	RESIDUAL
71.67	0.54	0.39	0.349
68.02	0.46	0.39	0.296
66.94	0.35	0.33	0.037
80.92	0.20	0.59	-0.898
90.88	1.46	0.64	0.787
95.06	0.58	0.79	-0.258
128.84	1.01	1.95	-0.662
149.61	7.29	3.59	0.725
119.84	1.04	1.51	-0.377

COEFFICIENT OF LINEAR CORRELATION = 0.8178
COEFFICIENT OF DETERMINATION=66.88PERCENT

F(CALC)	F(2,5PCENT)	F(CALC)	F(5PCENT)
14.1322	8.0727	14.1322	5.5914
SIGNIFICANT		SIGNIFICANT	

STANDARD ERROR OF THE ESTIMATE = 0.633

SHOE LOSS

PERC LOSS= 3.416-001(1.007+000)EXP(FEED)

FEEDRATE	MEASURED LOSS	CALCULATED LOSS	RESIDUAL
71.67	0.87	0.56	0.446
68.02	0.66	0.54	0.189
66.94	0.43	0.54	-0.216
80.92	0.35	0.59	-0.532
90.88	0.95	0.63	0.408
95.06	0.49	0.65	-0.287
128.84	0.63	0.82	-0.259
149.61	1.17	0.95	0.208
119.84	0.81	0.77	0.042

COEFFICIENT OF LINEAR CORRELATION = 0.5098
COEFFICIENT OF DETERMINATION=25.99PERCENT

F(CALC)	F(2,5PCENT)	F(CALC)	F(5PCENT)
2.4580	8.0727	2.4580	5.5914
NOT SIGNIFICANT		NOT SIGNIFICANT	

STANDARD ERROR OF THE ESTIMATE = 0.363

CYLINDER LOSS

PERC LOSS= 1.805-001(1.020+000)EXP(FEED)

FEEDRATE	MEASURED LOSS	CALCULATED LOSS	RESIDUAL
71.67	0.76	0.73	0.042
68.02	0.49	0.68	-0.323
66.94	0.78	0.67	0.161
80.92	0.73	0.87	-0.185
90.88	2.21	1.06	0.733
95.06	0.89	1.15	-0.253
128.84	1.31	2.22	-0.532
149.61	4.13	3.33	0.214
119.84	2.15	1.87	0.142

COEFFICIENT OF LINEAR CORRELATION = 0.8390
COEFFICIENT OF DETERMINATION=70.39PERCENT

F(CALC)	F(2,5PCENT)	F(CALC)	F(5PCENT)
16.6383	8.0727	16.6383	5.5914
SIGNIFICANT		SIGNIFICANT	

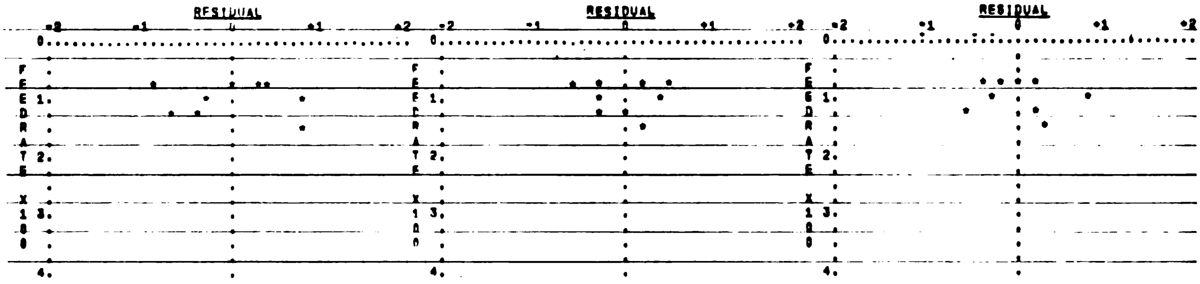
STANDARD ERROR OF THE ESTIMATE = 0.399

LIMITS OF PREDICTION

FEEDRATE	A
71.67	1.32
68.02	1.33
66.94	1.34
80.92	1.29
90.88	1.27
95.06	1.27
128.84	1.35
149.61	1.47
119.84	1.31

FEEDRATE	A
71.67	0.75
68.02	0.76
66.94	0.77
80.92	0.74
90.88	0.73
95.06	0.73
128.84	0.77
149.41	0.85
119.84	0.75

FEEDRATE	A
71.67	0.83
68.02	0.84
66.94	0.84
80.92	0.81
90.88	0.80
95.06	0.80
128.84	0.85
149.61	0.93
119.84	0.82



MF 82 AMS=10 2 WHEAT SELKIRK WINDROW 3 ARCOLA 17-8-64

REGRESSING GRAIN/STRAW ON FEEDRATE

LINEAR FIT

GRAIN/STRAW= 1.260+000 -3.805-003(FEEDRATE)
COEFFICIENT OF LINEAR CORRELATION =-0.6196
COEFFICIENT OF DETERMINATION=38.39PERCENT

EXPONENTIAL FIT

LN(GRAIN/STRAW)= 1.876+000 -4.435-001(LN(FEEDRATE))
COEFFICIENT OF LINEAR CORRELATION =-0.6070
COEFFICIENT OF DETERMINATION=36.84PERCENT

REGRESSING LOSS RESIDUALS ON GRAIN/STRAW RESIDUALS

LINEAR FIT

RACK LOSS
(LOSS RESIDUAL)=-5.126+000(G/S RESIDUAL)

SHOE LOSS
(LOSS RESIDUAL)=-1.471+000(G/S RESIDUAL)

CYLINDER LOSS
(LOSS RESIDUAL)=-3.049+000(G/S RESIDUAL)

EXPONENTIAL FIT

RACK LOSS
LN(LOSS RESIDUAL)=-3.177+000(LN(G/S RES))

SHOE LOSS
LN(LOSS RESIDUAL)=-1.835+000(LN(G/S RES))

CYLINDER LOSS
LN(LOSS RESIDUAL)=-1.520+000(LN(G/S RES))

SIMPLE EXPONENTIAL FIT AND CALCULATIONS FOR CONVERSION TO MULTIPLE CORRELATION
FIGURE 15

WF 82 AMS=10 3 WHEAT SELKIRK WINDROW 3 ARCOLA 17-8-64

MULTIPLE CORRELATION

LINEAR MODEL

BACK LOSS	SHOE LOSS	CYLINDER LOSS
PL= 2.494+000+ 3.628-002FEED -5.126+000G/S	PL= 2.085+000 -6.853-004FEED -1.471+000G/S	PL= 2.207+000+ 2.071-002FEED -3.849+000G/S

SIMPLE CORRELATION COEFFICIENT - LOSS ON GRAIN/STRAW

BACK LOSS	SHOE LOSS	CYLINDER LOSS
COEFFICIENT OF LINEAR CORRELATION =-0.7155	COEFFICIENT OF LINEAR CORRELATION =-0.9572	COEFFICIENT OF LINEAR CORRELATION =-0.7983
COEFFICIENT OF DETERMINATION=51.20PERCENT	COEFFICIENT OF DETERMINATION=91.62PERCENT	COEFFICIENT OF DETERMINATION=63.73PERCENT

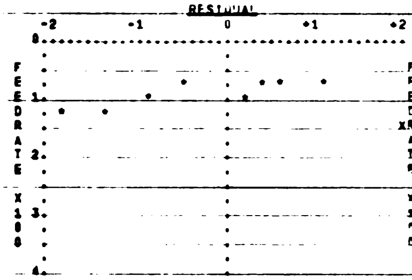
COEFFICIENTS OF MULTIPLE CORRELATION

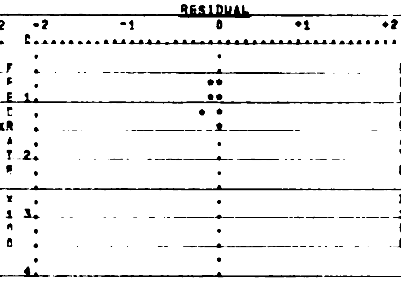
BACK LOSS	SHOE LOSS	CYLINDER LOSS
COEFFICIENT MULTIPLE CORRELATION = 0.8091	COEFFICIENT MULTIPLE CORRELATION = 0.9591	COEFFICIENT MULTIPLE CORRELATION = 0.8980
COEFFICIENT OF DETERMINATION=65.46PERCENT	COEFFICIENT OF DETERMINATION=91.98PERCENT	COEFFICIENT OF DETERMINATION=80.65PERCENT
STANDARD ERROR OF THE ESTIMATE = 1.513	STANDARD ERROR OF THE ESTIMATE = 0.087	STANDARD ERROR OF THE ESTIMATE = 0.593

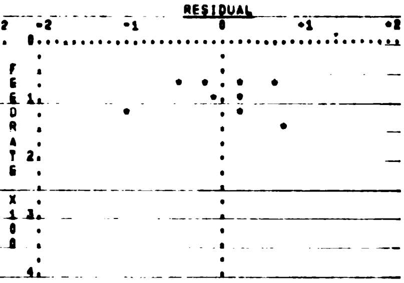
ADDITIONAL REGRESSION DUE TO GRAIN/STRAW

F(CALC)	F(2.5PCENT)	F(CALC)	F(5PCENT)	F(CALC)	F(2.5PCENT)	F(CALC)	F(5PCENT)	F(CALC)	F(2.5PCENT)	F(CALC)	F(5PCENT)
20.4565	8.8131	20.4565	5.9874	119.9562	8.8131	119.9562	5.9874	45.2040	8.8131	45.2040	5.9874
SIGNIFICANT		SIGNIFICANT		SIGNIFICANT		SIGNIFICANT		SIGNIFICANT		SIGNIFICANT	

FEEDRATE	MEASURED LOSS	CALCULATED LOSS	RESIDUAL	FEEDRATE	MEASURED LOSS	CALCULATED LOSS	RESIDUAL	FEEDRATE	MEASURED LOSS	CALCULATED LOSS	RESIDUAL
71.67	0.54	0.98	-0.437	71.67	0.87	0.86	0.014	71.67	0.76	1.25	-0.485
68.02	0.46	-0.05	0.517	68.02	0.66	0.60	0.056	68.02	0.49	0.63	-0.142
66.94	0.35	-0.70	1.054	66.94	0.43	0.42	0.010	66.94	0.78	0.25	0.535
80.92	0.20	-0.16	0.368	80.92	0.35	0.42	-0.076	80.92	0.73	0.56	0.170
90.88	1.46	2.28	-0.823	90.88	0.95	1.01	-0.061	90.88	2.21	2.00	0.208
95.06	0.58	0.44	0.135	95.06	0.49	0.44	0.049	95.06	0.89	0.90	-0.011
128.84	1.01	2.90	-1.896	128.84	0.63	0.77	-0.139	128.84	1.31	2.34	-1.033
149.61	7.29	4.65	2.431	149.61	1.17	1.10	0.063	149.61	4.13	3.48	0.647
119.84	1.04	2.39	-1.349	119.84	0.81	0.72	0.082	119.84	2.15	2.04	0.111







MULTIPLICATIVE MODEL

BACK LOSS	SHOE LOSS	CYLINDER LOSS
LNPL=-6.790+000+ 1.350+000LNF -3.177+000LNGS	LNPL= 7.655-002 -1.625-001LNF -1.835+000LNGS	LNPL=-5.822+000+ 1.278+000LNF -1.529+000LNGS
PL= 1.125-003(FR)EXP 1.350(G/S)EXP-3.177+000	PL= 1.080+000(FR)EXP-0.163(G/S)EXP-1.835+000	PL= 2.961-003(FR)EXP 1.278(G/S)EXP-1.529+000

SIMPLE CORRELATION COEFFICIENT - LOSS ON GRAIN/STRAW

BACK LOSS	SHOE LOSS	CYLINDER LOSS
COEFFICIENT OF LINEAR CORRELATION =-0.8944	COEFFICIENT OF LINEAR CORRELATION =-0.9240	COEFFICIENT OF LINEAR CORRELATION =-0.8100
COEFFICIENT OF DETERMINATION=80.35PERCENT	COEFFICIENT OF DETERMINATION=85.37PERCENT	COEFFICIENT OF DETERMINATION=65.61PERCENT

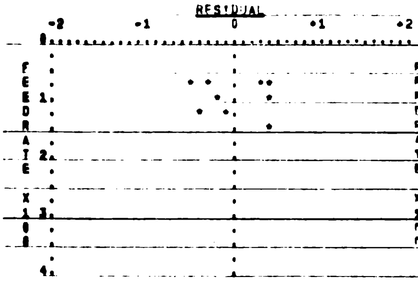
COEFFICIENTS OF MULTIPLE CORRELATION

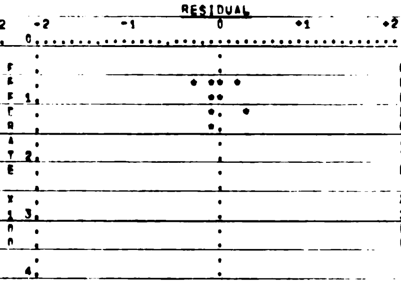
BACK LOSS	SHOE LOSS	CYLINDER LOSS
COEFFICIENT MULTIPLE CORRELATION = 0.9473	COEFFICIENT MULTIPLE CORRELATION = 0.9290	COEFFICIENT MULTIPLE CORRELATION = 0.9192
COEFFICIENT OF DETERMINATION=89.73PERCENT	COEFFICIENT OF DETERMINATION=86.30PERCENT	COEFFICIENT OF DETERMINATION=84.49PERCENT
STANDARD ERROR OF THE ESTIMATE = 0.381	STANDARD ERROR OF THE ESTIMATE = 0.169	STANDARD ERROR OF THE ESTIMATE = 0.312

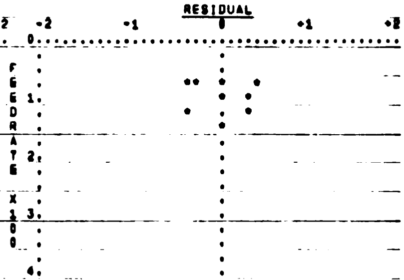
ADDITIONAL REGRESSION DUE TO GRAIN/STRAW

F(CALC)	F(2.5PCENT)	F(CALC)	F(5PCENT)	F(CALC)	F(2.5PCENT)	F(CALC)	F(5PCENT)	F(CALC)	F(2.5PCENT)	F(CALC)	F(5PCENT)
105.0528	8.8131	105.0528	5.9874	66.6589	8.8131	66.6589	5.9874	62.2533	8.8131	62.2533	5.9874
SIGNIFICANT		SIGNIFICANT		SIGNIFICANT		SIGNIFICANT		SIGNIFICANT		SIGNIFICANT	

FEEDRATE	MEASURED LOSS	CALCULATED LOSS	RESIDUAL	FEEDRATE	MEASURED LOSS	CALCULATED LOSS	RESIDUAL	FEEDRATE	MEASURED LOSS	CALCULATED LOSS	RESIDUAL
71.67	0.54	0.73	-0.288	71.67	0.87	0.81	0.074	71.67	0.76	0.97	-0.246
68.02	0.46	0.34	0.255	68.02	0.66	0.57	0.147	68.02	0.49	0.67	-0.312
66.94	0.35	0.24	0.353	66.94	0.43	0.46	-0.056	66.94	0.78	0.55	0.348
80.92	0.20	0.32	-0.459	80.92	0.35	0.45	-0.257	80.92	0.73	0.71	0.022
90.88	1.46	1.65	-0.126	90.88	0.95	1.04	-0.085	90.88	2.21	1.68	0.275
95.06	0.58	0.42	0.313	95.06	0.49	0.45	0.080	95.06	0.89	0.89	-0.001
128.84	1.01	1.43	-0.348	128.84	0.63	0.69	-0.080	128.84	1.31	1.95	-0.400
149.61	7.29	4.97	0.382	149.61	1.17	1.23	-0.052	149.61	4.13	3.90	0.056
119.84	1.04	1.13	-0.082	119.84	0.81	0.64	0.229	119.84	2.15	1.66	0.258







MULTIPLE LINEAR FIT AND MULTIPLICATIVE FIT
FIGURE 16

RESULTS AND DISCUSSION

Best-Fit Models

Rack loss

Table 3 illustrates the results of comparing rack loss data using the five proposed correlation models. The table summarizes the results from nineteen comparisons in wheat, ten in barley, thirteen in oats and twelve in rye.

In fields of constant grain/straw ratio, the exponential model was the best fit if loss tests were conducted over a reasonably large range of feedrates; if the runs were all conducted at the lower end of the feedrate range, the linear model was the best fit.

Considering simple correlations (loss on feedrate), the exponential model usually gave better fits than the simple exponential model. In the three cases in which the simple exponential model produced the best fit, it was only slightly better than the exponential model.

In fields of varying grain yield and varying straw yield, the multiplicative model produced the best fit, if the loss tests were conducted over a reasonably large range of feedrates; otherwise, the multiple linear model produced the best fit.

In barley, linear models gave very poor fits, in all cases. This was due to straw break-up resulting in rack overloading at low feedrates.

Table 3. Best-Fit Models for Rack Loss Data

Crop	Number of Machine-Crop Combinations	Model	Frequency of Model for Best Fit	Comment
Wheat	19	simple linear	2	low feedrates, uniform fields
		exponential	2	large feedrate range, uniform fields
		simple exponential	0	
		multiple linear	6	low feedrates, varying G/S
		multiplicative	9	large feedrate range, varying G/S
Barley	10	simple linear	0	
		exponential	2	uniform fields
		simple exponential	0	
		multiple linear	0	
		multiplicative	8	varying G/S
Oats	13	simple linear	0	
		exponential	5	large feedrate range, uniform fields
		simple exponential	0	
		multiple linear	2	low feedrate range, varying G/S
		multiplicative	6	large feedrate range, varying G/S
Rye	12	simple linear	4	low maximum feedrate, uniform fields
		exponential	2	large feedrate range, uniform fields
		simple exponential	3	large feedrate range, uniform fields
		multiple linear	1	low maximum feedrate, varying G/S
		multiplicative	2	large feedrate range, varying G/S

Shoe loss

Table 4 illustrates the results of comparing shoe loss data, using the five correlations models.

Although grain/straw variation influenced shoe loss, its influence was not as great as in the case of rack loss. Exponential models produced better fits than linear models only in those cases having high shoe loads (much chaff and straw break-up). The fact that linear models produced the best fit in oats, in twelve out of thirteen cases, is explained by the low shoe load. (The chaff consists mainly of glumes which offer little hindrance to separation.)

Cylinder loss

The results of comparison of cylinder loss data, using the five correlation models, is shown in Table 5. The exponential model gave a better fit than the simple linear model only in hard-to-thresh crops, when the range of feedrates obtained in the test was large. When loss tests were conducted in easy-to-thresh crops and all runs were at relatively low feedrates, the simple linear model produced the best fit. The inclusion of grain/straw variation significantly improved the fits in non-uniform fields.

The ease of removal of kernels from the heads and "slugging" of the cylinder at low feedrates, explain why linear models usually produced the best fit for cylinder loss data in oats and rye.

Table 4. Best-Fit Models for Shoe Loss Data

Crop	Number of Machine-Crop Combinations	Model	Frequency of Model for Best Fit	Comment
Wheat	19	simple linear	10	low shoe load, uniform fields
		exponential	0	
		simple exponential	0	
		multiple linear	6	low shoe load, varying G/S
		multiplicative	3	brittle straw, high shoe load, varying G/S
Barley	10	simple linear	5	low shoe load, uniform fields
		exponential	3	high shoe load, uniform fields
		simple exponential	0	
		multiple linear	0	
		multiplicative	2	high shoe load, large variation in G/S
Oats	13	simple linear	6	low shoe load, uniform fields
		exponential	0	
		simple exponential	0	
		multiple linear	6	low shoe load, varying G/S
		multiplicative	1	
Rye	12	simple linear	8	low range of feedrates
		exponential		
		simple exponential		
		multiple linear	1	low range of feedrates
		multiplicative	3	large feedrate range, dry brittle crop

Table 5. Best-Fit Models for Cylinder Loss Data

Crop	Number of Machine-Crop Combinations	Model	Frequency of Model for Best Fit	Comment
Wheat	19	simple linear	5	easy-to-thresh
		exponential	4	hard-to-thresh, large range of feedrates
		simple exponential	0	
		multiple linear	6	easy-to-thresh, varying G/S
		multiplicative	4	hard-to-thresh, varying G/S
Barley	10	simple linear	3	easy-to-thresh
		exponential	0	
		simple exponential	0	
		multiple linear	4	easy-to-thresh, varying G/S
		multiplicative	3	hard-to-thresh, varying G/S
Oats	9	simple linear	5	easy-to-thresh
		exponential	0	
		simple exponential	0	
		multiple linear	3	easy-to-thresh, varying G/S
		multiplicative	1	
Rye	8	simple linear	4	easy-to-thresh
		exponential	0	
		simple exponential	0	
		multiple linear	2	easy-to-thresh, varying G/S
		multiplicative	2	

Dependence of Loss on Grain/Straw Variation

In all crops and all crop conditions (fifty-four machine-crop combinations) the sign of the simple correlation coefficient, r_{yx_2}, (loss regressed on grain/straw, disregarding variation in feedrate) was negative, whenever there was any appreciable variation in grain/straw ratio in the test field. Considering all combinations, the sign was negative in 85% of the cases for rack loss, in 76% of the cases for shoe loss and in 85% of the cases for cylinder loss. In those cases in which r_{yx_2} was positive, the variation in grain/straw ratio was small and additional regression due to grain/straw variation was insignificant. A decrease in grain/straw ratio should, therefore, result in an increase in percent loss, at a constant feedrate, if other crop variables are held constant.

Results of the multiple regression indicated that a decrease in grain/straw ratio resulted in an increase in percent loss in all cases in wheat and rye and in most cases in oats and barley. In three non-uniform fields of oats and in six non-uniform fields of barley, however, increases in grain/straw ratio, resulted in increases in loss. This may be explained as follows: In non-uniform fields of oats and barley, high grain/straw ratio may be associated with short brittle straw, whereas low grain straw ratio may be associated with tall rank straw. Hence, in such fields, grain/straw ratio may be a direct indication of straw break-up and resultant separation load.

Inclusion of grain/straw variation significantly improved rack loss fits in thirty-four cases (63%), significantly improved shoe loss fits in twenty-two cases (40%) and significantly improved cylinder loss fits in twenty-five cases (46%). This indicates that grain/straw variation should be considered in analyzing loss data. Its affect can be neglected only in uniform fields (fields of constant grain yield and constant straw yield).

Feedrate or Throughput as an Independent Variable

In fifty four machine-crop combinations data was analyzed using both feedrate and throughput as the first independent variable. (i.e., The first analysis considered loss = f_1 (feedrate, grain/straw) while the second analysis considered loss = f_2 (throughput, grain/straw).)

Comparison between the two methods of analysis revealed the following:

1. For ideal fields (constant grain/straw ratio) both methods resulted in equally good fits.

2. In fields of varying grain/straw ratio, the simple correlation of loss on feedrate usually resulted in much better fits than the simple correlation of loss on throughput. This was true for rack loss, shoe loss and cylinder loss in all four crop types. In other words, the regression of loss on feedrate accounted for a greater percentage of the variation in loss than did the regression of loss on throughput.

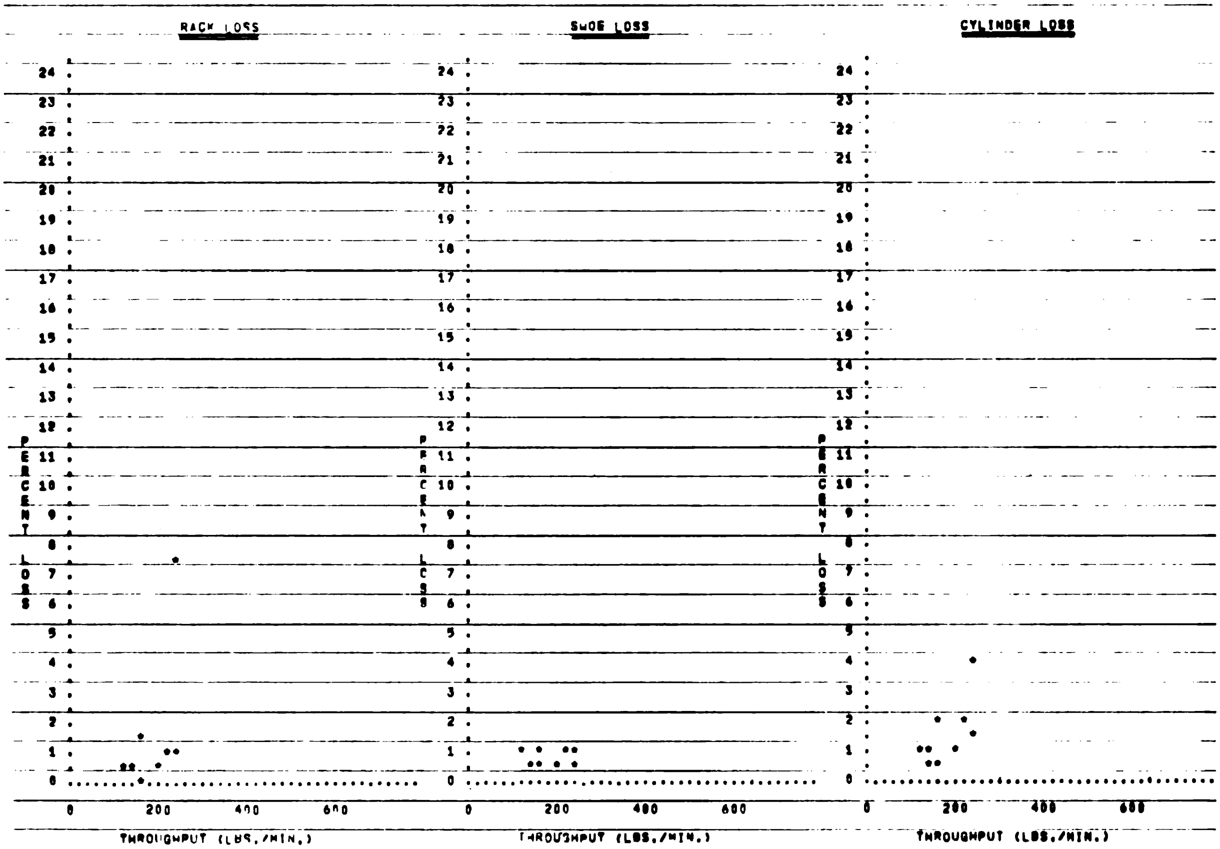
3. When variation due to grain/straw was introduced, the multiple correlations, loss = f_1 (feedrate, grain/straw) and loss = f_2 (throughput, grain/straw), both resulted in equally good fits.

MACHINE	MODEL	TEST NUMBER	SERIES	CROP	VARIETY	WINDROW OR STAND	STRAW	LOCATION	DATE
MF	82	AMS-10	2	WHEAT	SELKIRK	WINDROW	3	ARCOLA	17-8-64

RUN	WIDTH (FEET)	DISTANCE (FEET)	TIME (MINUTES)	STRAW AND LOSS (POUNDS)	CHAFF AND LOSS (POUNDS)	GRAIN COLLECTED (POUNDS)	RACK LOSS (POUNDS)	SHOE LOSS (POUNDS)	CYLINDER LOSS (POUNDS)
1	12.00	73.00	0.48	31.00	4.00	27.00	0.15	0.24	0.21
2	12.00	62.00	0.59	34.00	4.00	36.00	0.17	0.24	0.18
3	12.00	51.00	0.47	30.00	2.00	34.00	0.12	0.15	0.27
4	12.00	66.00	0.39	28.00	4.00	34.00	0.07	0.12	0.25
5	12.00	62.00	0.32	28.00	2.00	19.00	0.29	0.19	0.44
6	12.00	44.00	0.34	30.00	3.00	34.00	0.20	0.17	0.31
7	12.00	55.00	0.25	31.00	2.00	26.00	0.27	0.17	0.35
8	12.00	42.00	0.23	34.00	1.00	18.00	1.50	0.24	0.85
9	12.00	67.00	0.25	29.00	2.00	25.00	0.27	0.21	0.56

RUN	STRAW AND CHAFF (LBS.)	TOTAL GRAIN (LBS.)	THROUGHPUT (LBS./MIN.)	RACK LOSS (PERCENT)	SHOE LOSS (PERCENT)	CYLINDER LOSS (PERCENT)	SPEED (MILE/HOUR)	WORK RATE (ACRE/HOUR)	GRAIN YIELD (LBS./ACRE)	GRAIN/STRAW RATIO
1	34.40	27.60	129.17	0.54	0.87	0.76	1.73	2.51	1372.44	0.80
2	37.41	36.59	134.95	0.46	0.66	0.49	1.28	1.86	2142.29	0.98
3	31.46	34.54	140.43	0.35	0.43	0.78	1.23	1.79	2458.44	1.10
4	31.56	34.44	169.23	0.20	0.35	0.73	1.92	2.80	1894.20	1.09
5	29.08	19.92	151.13	1.44	0.95	2.21	2.20	3.20	1166.20	0.69
6	32.32	34.68	197.06	0.58	0.49	0.89	1.47	2.14	2861.10	1.07
7	32.21	26.79	236.00	1.01	0.63	1.31	2.50	3.64	1768.14	0.83
8	34.41	20.59	239.13	7.29	1.17	4.13	2.08	3.02	1779.56	0.60
9	29.96	26.04	224.00	1.04	0.81	2.15	3.05	4.43	1410.82	0.87

MF 82 AMS-10 2 WHEAT SELKIRK WINDROW 3 ARCOLA 17-8-64



RAW DATA, INITIAL CALCULATIONS AND SCATTER DIAGRAMS
(THROUGHPUT BASIS)
FIGURE 17

MF 82 AMS-1A 2 MMBAT SELKIRK WINDROW 3 ARCOLA 17-8-64

FITTING A LINEAR FUNCTION , Y=A+BX

RACK LOSS

PERCENT LOSS=-3.493-000+ 2.734-002(THRU)

THROUGHPUT	MEASURED LOSS	CALCULATED LOSS	RESIDUAL
129.17	0.54	0.04	0.506
134.55	0.46	0.18	0.280
140.43	0.35	0.35	0.002
169.23	0.20	1.13	-0.930
153.13	1.44	0.69	0.743
197.06	0.58	1.89	-1.317
236.00	1.01	2.96	-1.951
239.13	7.29	3.04	4.241
224.00	1.04	2.61	-1.593

COEFFICIENT OF LINEAR CORRELATION = 0.5470
COEFFICIENT OF DETERMINATION=29.92PERCENT

F(CALC)	F(2.5PCENT)	F(CALC)	F(5PCENT)
2.9893	8.0727	2.9893	5.5914
NOT SIGNIFICANT		NOT SIGNIFICANT	

STANDARD ERROR OF THE ESTIMATE = 1.995

SHOE LOSS

PERCENT LOSS= 4.144-001+ 1.623-003(THRU)

THROUGHPUT	MEASURED LOSS	CALCULATED LOSS	RESIDUAL
129.17	0.87	0.62	0.246
134.55	0.66	0.63	0.024
140.43	0.43	0.64	-0.208
169.23	0.35	0.69	-0.340
153.13	0.95	0.66	0.291
197.06	0.49	0.73	-0.244
236.00	0.63	0.80	-0.162
239.13	1.17	0.80	0.364
224.00	0.81	0.78	0.029

COEFFICIENT OF LINEAR CORRELATION = 0.2722
COEFFICIENT OF DETERMINATION= 7.41PERCENT

F(CALC)	F(2.5PCENT)	F(CALC)	F(5PCENT)
0.5602	8.0727	0.5602	5.5914
NOT SIGNIFICANT		NOT SIGNIFICANT	

STANDARD ERROR OF THE ESTIMATE = 0.273

CYLINDER LOSS

PERCENT LOSS=-1.497+000+ 1.099-002(THRU)

THROUGHPUT	MEASURED LOSS	CALCULATED LOSS	RESIDUAL
129.17	0.76	0.65	0.112
134.55	0.49	0.74	-0.243
140.43	0.78	0.83	-0.051
169.23	0.73	1.31	-0.585
153.13	2.21	1.04	1.165
197.06	0.89	1.77	-0.878
236.00	1.31	2.42	-1.112
239.13	4.13	2.47	1.658
224.00	2.15	2.22	-0.069

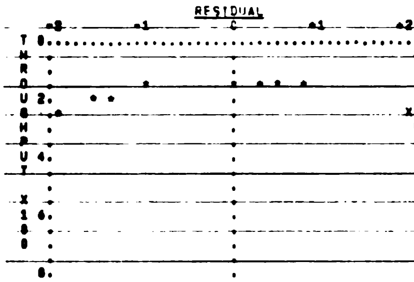
COEFFICIENT OF LINEAR CORRELATION = 0.6934
COEFFICIENT OF DETERMINATION=48.12PERCENT

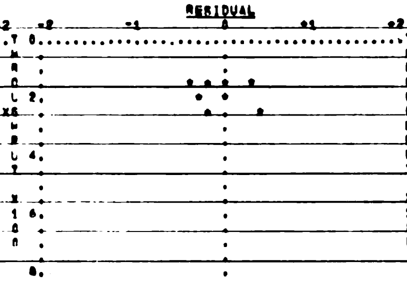
F(CALC)	F(2.5PCENT)	F(CALC)	F(5PCENT)
4.6095	8.0727	4.6095	5.5914
NOT SIGNIFICANT		NOT SIGNIFICANT	

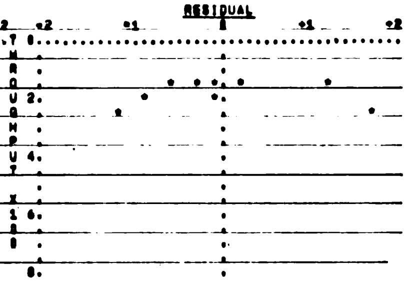
STANDARD ERROR OF THE ESTIMATE = 0.966

LIMITS OF PREDICTION

THROUGHPUT	A (RACK LOSS)	A (SHOE LOSS)	A (CYLINDER LOSS)
129.17	4.27	0.59	2.07
134.55	4.21	0.58	2.04
140.43	4.14	0.57	2.02
169.23	4.08	0.55	1.94
153.13	4.07	0.56	1.97
197.06	4.02	0.55	1.95
236.00	4.32	0.59	2.09
239.13	4.34	0.60	2.11
224.00	4.19	0.57	2.03







FITTING AN EXPONENTIAL FUNCTION , Y=A(X)EXP(B)

RACK LOSS

PERCENT LOSS= 2.709-006(THRU PUT)EXP 2.434

THROUGHPUT	MEASURED LOSS	CALCULATED LOSS	RESIDUAL
129.17	0.54	0.37	0.377
134.55	0.46	0.41	0.121
140.43	0.35	0.46	-0.274
169.23	0.20	0.72	-1.264
153.13	1.46	0.54	0.940
197.06	0.58	1.04	-0.592
236.00	1.01	1.62	-0.473
239.13	7.29	1.67	1.473
224.00	1.04	1.42	-0.317

COEFFICIENT OF LINEAR CORRELATION = 0.5854
COEFFICIENT OF DETERMINATION=34.27PERCENT

F(CALC)	F(2.5PCENT)	F(CALC)	F(5PCENT)
3.6504	8.0727	3.6504	5.5914
NOT SIGNIFICANT		NOT SIGNIFICANT	

STANDARD ERROR OF THE ESTIMATE = 0.892

SHOE LOSS

PERCENT LOSS= 1.197-001(THRU PUT)EXP 0.331

THROUGHPUT	MEASURED LOSS	CALCULATED LOSS	RESIDUAL
129.17	0.87	0.60	0.376
134.55	0.66	0.61	0.080
140.43	0.43	0.61	-0.346
169.23	0.35	0.65	-0.628
153.13	0.95	0.63	0.412
197.06	0.49	0.69	-0.337
236.00	0.63	0.73	-0.139
239.13	1.17	0.73	0.465
224.00	0.81	0.72	0.118

COEFFICIENT OF LINEAR CORRELATION = 0.2073
COEFFICIENT OF DETERMINATION= 4.30PERCENT

F(CALC)	F(2.5PCENT)	F(CALC)	F(5PCENT)
0.3142	8.0727	0.3142	5.5914
NOT SIGNIFICANT		NOT SIGNIFICANT	

STANDARD ERROR OF THE ESTIMATE = 0.413

CYLINDER LOSS

PERCENT LOSS= 7.161-005(THRU PUT)EXP 1.881

THROUGHPUT	MEASURED LOSS	CALCULATED LOSS	RESIDUAL
129.17	0.76	0.67	0.127
134.55	0.49	0.72	-0.386
140.43	0.78	0.78	-0.003
169.23	0.73	1.11	-0.420
153.13	2.21	0.92	0.873
197.06	0.89	1.46	-0.496
236.00	1.31	2.08	-0.466
239.13	4.13	2.13	0.660
224.00	2.15	1.89	0.130

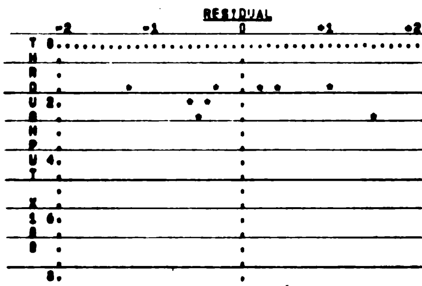
COEFFICIENT OF LINEAR CORRELATION = 0.6784
COEFFICIENT OF DETERMINATION=46.02PERCENT

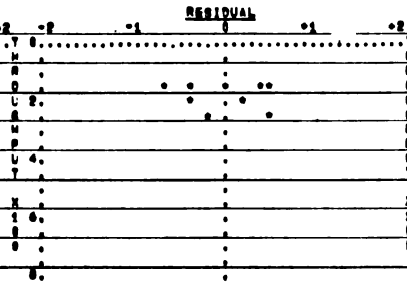
F(CALC)	F(2.5PCENT)	F(CALC)	F(5PCENT)
5.9698	8.0727	5.9698	5.5914
NOT SIGNIFICANT		SIGNIFICANT	

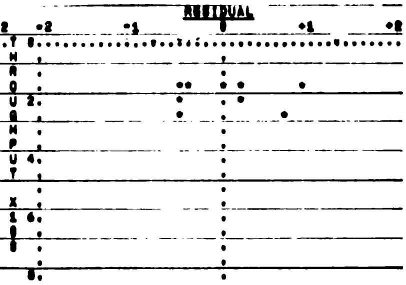
STANDARD ERROR OF THE ESTIMATE = 0.539

LIMITS OF PREDICTION

THROUGHPUT	A (RACK LOSS)	A (SHOE LOSS)	A (CYLINDER LOSS)
129.17	1.93	0.89	1.17
134.55	1.89	0.88	1.14
140.43	1.85	0.86	1.13
169.23	1.74	0.83	1.08
153.13	1.81	0.84	1.10
197.06	1.89	0.84	1.09
236.00	1.92	0.89	1.16
239.13	1.93	0.89	1.17
224.00	1.89	0.87	1.13







LINEAR FIT AND EXPONENTIAL FIT
(THROUGHPUT BASIS)
FIGURE 18

MF 82 AMS=10 2 WHEAT SELKIRK WINDROW 3 ARCOLA 17-8-64

FITTING A SIMPLE EXPONENTIAL FUNCTION , Y=A(B)EXP(X)

RACK LOSS

PERC LOSS= 6.107-002(1.014+000)EXP(THRU)

THROUGHPUT	MEASURED LOSS	CALCULATED LOSS	RESIDUAL
129.17	0.54	0.39	0.356
134.55	0.46	0.41	0.123
140.43	0.35	0.45	-0.251
169.23	0.20	0.67	-1.195
153.13	1.45	0.53	1.002
197.06	0.59	1.01	-0.547
236.00	1.01	1.73	-0.540
239.13	7.29	1.81	1.394
224.00	1.04	1.46	-0.342

COEFFICIENT OF LINEAR CORRELATION = 0.6137
COEFFICIENT OF DETERMINATION=37.67PERCENT

F(CALC)	F(2.5PCENT)	F(CALC)	F(5PCENT)
4.2296	8.0727	4.2236	5.5914
NOT SIGNIFICANT		NOT SIGNIFICANT	

STANDARD ERROR OF THE ESTIMATE = 0.849

SHOE LOSS

PERC LOSS= 4.447-001(1.002+000)EXP(THRU)

THROUGHPUT	MEASURED LOSS	CALCULATED LOSS	RESIDUAL
129.17	0.87	0.59	0.387
134.55	0.66	0.60	0.093
140.43	0.43	0.61	-0.332
169.23	0.35	0.65	-0.616
153.13	0.95	0.62	0.427
197.06	0.49	0.69	-0.336
236.00	0.63	0.75	-0.163
239.13	1.17	0.75	0.438
224.00	0.81	0.73	0.103

COEFFICIENT OF LINEAR CORRELATION = 0.2482
COEFFICIENT OF DETERMINATION= 6.16PERCENT

F(CALC)	F(2.5PCENT)	F(CALC)	F(5PCENT)
0.4594	8.0727	0.4594	5.5914
NOT SIGNIFICANT		NOT SIGNIFICANT	

STANDARD ERROR OF THE ESTIMATE = 0.409

CYLINDER LOSS

PERC LOSS= 1.774-001(1.011+000)EXP(THRU)

THROUGHPUT	MEASURED LOSS	CALCULATED LOSS	RESIDUAL
129.17	0.76	0.69	0.091
134.55	0.49	0.74	-0.402
140.43	0.78	0.78	-0.001
169.23	0.73	1.06	-0.379
153.13	2.21	0.89	0.904
197.06	0.89	1.42	-0.465
236.00	1.31	2.15	-0.497
239.13	4.13	2.22	0.620
224.00	2.15	1.89	0.128

COEFFICIENT OF LINEAR CORRELATION = 0.6863
COEFFICIENT OF DETERMINATION=47.11PERCENT

F(CALC)	F(2.5PCENT)	F(CALC)	F(5PCENT)
6.2344	8.0727	6.2344	5.5914
NOT SIGNIFICANT		SIGNIFICANT	

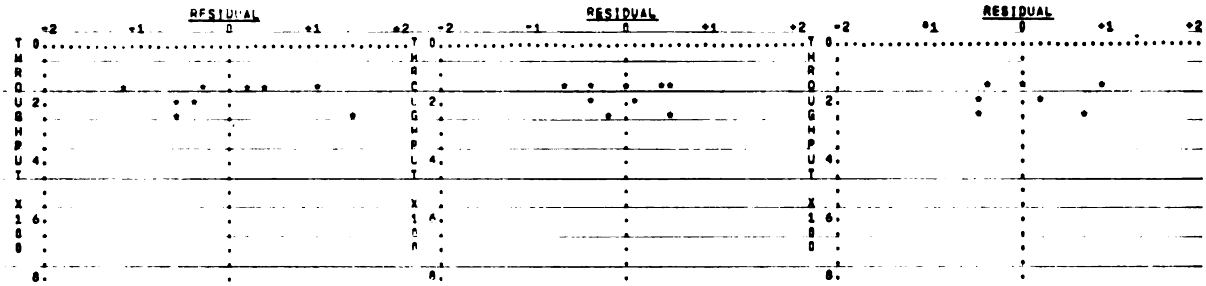
STANDARD ERROR OF THE ESTIMATE = 0.534

LIMITS OF PREDICTION

THROUGHPUT	A
129.17	1.84
134.55	1.84
140.43	1.81
169.23	1.74
153.13	1.77
197.06	1.75
236.00	1.89
239.13	1.97
224.00	1.83

THROUGHPUT	A
129.17	0.88
134.55	0.86
140.43	0.85
169.93	0.82
153.13	0.83
197.06	0.82
236.00	0.89
239.13	0.89
224.00	0.86

THROUGHPUT	A
129.17	1.14
134.55	1.13
140.43	1.11
169.23	1.07
153.13	1.09
197.06	1.07
236.00	1.16
239.13	1.17
224.00	1.12



MF 82 AMS=10 2 WHEAT SELKIRK WINDROW 3 ARCOLA 17-8-64

REGRESSING GRAIN/STRAW ON THRU PUT

LINEAR FIT

GRAIN/STRAW= 1.150+000 -1.429-003(THRU PUT)
COEFFICIENT OF LINEAR CORRELATION =-0.3511
COEFFICIENT OF DETERMINATION=12.33PERCENT

EXPONENTIAL FIT

LN(GRAIN/STRAW)= 1.328+000 -2.830-001(LN(THRU PUT))
COEFFICIENT OF LINEAR CORRELATION =-0.3264
COEFFICIENT OF DETERMINATION=10.66PERCENT

REGRESSING LOSS RESIDUALS ON GRAIN/STRAW RESIDUALS

LINEAR FIT

RACK LOSS
(LOSS RESIDUAL)=-7.332+000(G/S RESIDUAL)

SHOE LOSS
(LOSS RESIDUAL)=-1.440+000(G/S RESIDUAL)

CYLINDER LOSS
(LOSS RESIDUAL)=-4.228+000(G/S RESIDUAL)

EXPONENTIAL FIT

RACK LOSS
LN(LOSS RESIDUAL)=-3.786+000(LN(G/S RES))

SHOE LOSS
LN(LOSS RESIDUAL)=-1.764+000(LN(G/S RES))

CYLINDER LOSS
LN(LOSS RESIDUAL)=-2.107+000(LN(G/S RES))

SIMPLE EXPONENTIAL FIT AND CALCULATIONS FOR CONVERSION TO MULTIPLE CORRELATION (THROUGHPUT BASIS)
FIGURE 19

ME 82 ANS=10 2 WHEAT SELKIRK WINDROW 3 ARCOLA 17-8-64

MULTIPLE CORRELATION

LINEAR MODEL

BACK LOSS	SHOE LOSS	CYLINDER LOSS
PL= 4.935+000+ 1,686-002THRU -7,332+000G/S	PL= 2.069+000 -4,345-004THRU -1.440+000G/S	PL= 3.363+000+ 1.055-002THRU -4.228+000G/S

SIMPLE CORRELATION COEFFICIENT - LOSS ON GRAIN/STRAW

BACK LOSS	SHOE LOSS	CYLINDER LOSS
COEFFICIENT OF LINEAR CORRELATION =-0.7155	COEFFICIENT OF LINEAR CORRELATION =-0.9572	COEFFICIENT OF LINEAR CORRELATION =-0.7983
COEFFICIENT OF DETERMINATION=51,20PERCENT	COEFFICIENT OF DETERMINATION=91.62PERCENT	COEFFICIENT OF DETERMINATION=63.73PERCENT

COEFFICIENTS OF MULTIPLE CORRELATION

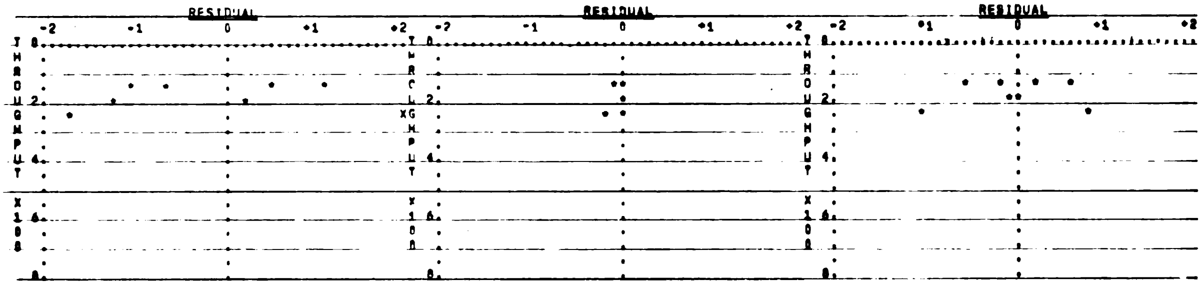
BACK LOSS	SHOE LOSS	CYLINDER LOSS
COEFFICIENT MULTIPLE CORRELATION = 0.7829	COEFFICIENT MULTIPLE CORRELATION = 0.9596	COEFFICIENT MULTIPLE CORRELATION = 0.8829
COEFFICIENT OF DETERMINATION=61.18PERCENT	COEFFICIENT OF DETERMINATION=92.09PERCENT	COEFFICIENT OF DETERMINATION=77.95PERCENT
STANDARD ERROR OF THE ESTIMATE = 1.604	STANDARD ERROR OF THE ESTIMATE = 0.086	STANDARD ERROR OF THE ESTIMATE = 0.633

ADDITIONAL REGRESSION DUE TO GRAIN/STRAW

F(CALC)	F(2.5PCENT)	F(CALC)	F(5PCENT)	F(CALC)	F(2.5PCENT)	F(CALC)	F(5PCENT)	F(CALC)	F(2.5PCENT)	F(CALC)	F(5PCENT)
19.2616	8.8131	19.2616	5.9874	116.8580	8.8131	116.8580	5.9874	43.0757	8.8131	43.0757	5.9874
SIGNIFICANT		SIGNIFICANT		SIGNIFICANT		SIGNIFICANT		SIGNIFICANT		SIGNIFICANT	

THROUGHPUT	MEASURED LOSS	CALCULATED LOSS	RESIDUAL	THROUGHPUT	MEASURED LOSS	CALCULATED LOSS	RESIDUAL	THROUGHPUT	MEASURED LOSS	CALCULATED LOSS	RESIDUAL
129.17	0.54	1.23	-0.687	129.17	0.87	0.86	0.012	129.17	0.76	1.33	-0.573
134.55	0.46	0.03	0.432	134.55	0.66	0.60	0.054	134.55	0.49	0.65	-0.155
140.43	0.35	-0.75	1.095	140.43	0.43	0.43	0.007	140.43	0.78	0.20	0.579
169.23	0.20	-0.21	0.416	169.23	0.35	0.42	-0.076	169.23	0.73	0.53	0.191
153.13	1.44	2.49	-1.038	153.13	0.95	1.02	-0.062	153.13	2.21	2.08	0.127
197.06	0.58	0.39	0.187	197.06	0.49	0.44	0.052	197.06	0.89	0.91	-0.011
236.00	1.01	2.82	-1.808	236.00	0.63	0.77	-0.134	236.00	1.31	2.34	-1.030
239.13	7.29	4.58	2.706	239.13	1.17	1.10	0.062	239.13	4.13	3.36	0.773
224.00	1.04	2.34	-1.302	224.00	0.81	0.72	0.086	224.00	2.15	2.05	0.099

RESIDUAL RESIDUAL RESIDUAL



MULTIPLICATIVE MODEL

BACK LOSS	SHOE LOSS	CYLINDER LOSS
LNPL=-7,791+000+ 1,363+000LNT -3,786+000LNGS	LNPL= 2,198-001 -1,685-001LNT -1,764+000LNGS	LNPL=-6.746+000+ 1.285+000LNT -2.187+000LNGS
PL= 4.135-004(TH)EXP 1.363(G/S)EXP-3.786+000	PL= 1.246+000(TH)EXP-0.168(G/S)EXP-1.764+000	PL= 1.175-003(TH)EXP 1.285(G/S)EXP-2.187+000

SIMPLE CORRELATION COEFFICIENT - LOSS ON GRAIN/STRAW

BACK LOSS	SHOE LOSS	CYLINDER LOSS
COEFFICIENT OF LINEAR CORRELATION =-0.8964	COEFFICIENT OF LINEAR CORRELATION =-0.9240	COEFFICIENT OF LINEAR CORRELATION =-0.8100
COEFFICIENT OF DETERMINATION=80,35PERCENT	COEFFICIENT OF DETERMINATION=85.37PERCENT	COEFFICIENT OF DETERMINATION=65.61PERCENT

COEFFICIENTS OF MULTIPLE CORRELATION

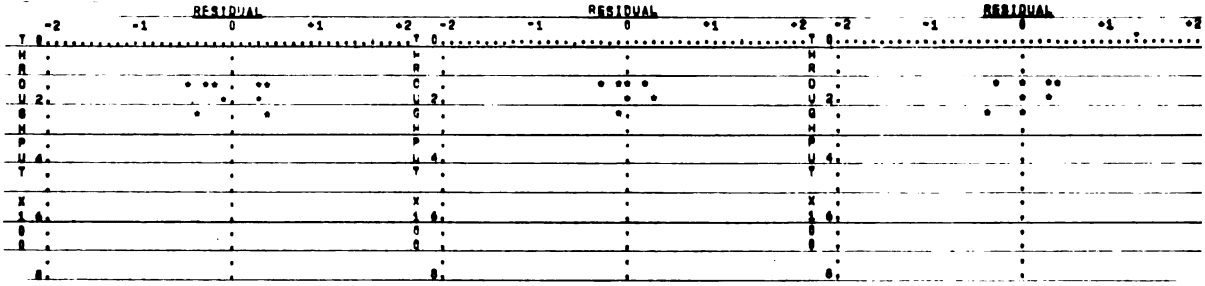
BACK LOSS	SHOE LOSS	CYLINDER LOSS
COEFFICIENT MULTIPLE CORRELATION = 0.9484	COEFFICIENT MULTIPLE CORRELATION = 0.9294	COEFFICIENT MULTIPLE CORRELATION = 0.9200
COEFFICIENT OF DETERMINATION=89,95PERCENT	COEFFICIENT OF DETERMINATION=86.37PERCENT	COEFFICIENT OF DETERMINATION=84.60PERCENT
STANDARD ERROR OF THE ESTIMATE = 0.377	STANDARD ERROR OF THE ESTIMATE = 0.168	STANDARD ERROR OF THE ESTIMATE = 0.309

ADDITIONAL REGRESSION DUE TO GRAIN/STRAW

F(CALC)	F(2.5PCENT)	F(CALC)	F(5PCENT)	F(CALC)	F(2.5PCENT)	F(CALC)	F(5PCENT)	F(CALC)	F(2.5PCENT)	F(CALC)	F(5PCENT)
110.5605	8,8131	110.5605	5,9874	61,1586	8,8131	61,1586	5.9874	68.1479	8.8131	68.1479	5.9874
SIGNIFICANT		SIGNIFICANT		SIGNIFICANT		SIGNIFICANT		SIGNIFICANT		SIGNIFICANT	

THROUGHPUT	MEASURED LOSS	CALCULATED LOSS	RESIDUAL	THROUGHPUT	MEASURED LOSS	CALCULATED LOSS	RESIDUAL	THROUGHPUT	MEASURED LOSS	CALCULATED LOSS	RESIDUAL
129.17	0.54	0.72	-0.277	129.17	0.87	0.81	0.071	129.17	0.76	0.96	-0.237
134.55	0.46	0.34	0.261	134.55	0.66	0.57	0.145	134.55	0.49	0.67	-0.308
140.43	0.35	0.25	0.349	140.43	0.43	0.46	-0.056	140.43	0.78	0.55	0.344
169.23	0.20	0.32	-0.464	169.23	0.35	0.45	-0.256	169.23	0.73	0.71	0.017
153.13	1.46	1.64	-0.122	153.13	0.95	1.04	-0.087	153.13	2.21	1.67	0.277
197.06	0.58	0.42	0.307	197.06	0.49	0.45	0.082	197.06	0.89	0.90	-0.006
236.00	1.01	1.42	-0.344	236.00	0.63	0.69	-0.079	236.00	1.31	1.94	-0.395
239.13	7.29	5.04	0.369	239.13	1.17	1.22	-0.050	239.13	4.13	3.95	0.045
224.00	1.04	1.12	-0.078	224.00	0.81	0.64	0.229	224.00	2.15	1.65	0.263

RESIDUAL RESIDUAL RESIDUAL



MULTIPLE LINEAR FIT AND MULTIPLICATIVE FIT
(THROUGHPUT BASIS)
FIGURE 20

Figures 17 to 20 represent output from the computer program, using the same data as was used in Figures 13 to 16, but with "throughput" as an independent variable, rather than "feedrate." Comparison of Figures 13 - 16 to Figures 17 - 20 illustrate the points listed above.

Comparing Tests Conducted in Different Years and Conditions

Loss surfaces

In an attempt to determine if important crop variables were not accounted for in the above analysis, all of the loss data for the standard combine was analyzed on the basis of crop type only. For example, the loss data from seven different fields of hard red spring wheat, collected over a four year period (fifty-nine individual loss collections) was checked for goodness of fit using the previous models. This analysis neglected any differences in moisture content, straw conditions and variety. It also neglected effects of climatic conditions on crop conditions.

The results of this analysis is as follows:

1. In wheat (seven crops, fifty nine collections) a reasonably good fit was obtained using the multiplicative model. The residual plots showed more scatter than in the case of analysis of individual fields, and the multiple correlation coefficients were much lower.

The final regression equations for the standard combine, in wheat, were:

$$\text{Rack loss} = 4.757 \times 10^{-4}\,(\text{feedrate})^{1.502}\,(\text{grain/straw})^{-1.688}$$

$$r_{yx_1}\ (\text{loss on feedrate}) = .7683$$

r_{yx_2} (loss on grain/straw) = - .7576

$r_{x_2x_1}$ (grain/straw on feedrate) = - .5809

R = .8582

C = 73.65%

Standard Error of Estimate = .737

Shoe loss = $1.019 \times 10^{-1} (\text{feedrate})^{0.320} (\text{grain/straw})^{-1.734}$

r_{yx_1} = .5600

r_{yx_2} = - .7893

$r_{x_2x_1}$ = - .5809

R = .7991

C = 63.86%

Standard Error of Estimate = .595

Cylinder loss = $1.159 \times 10^{-1} (\text{feedrate})^{0.370} (\text{grain/straw})^{-1.345}$

r_{yx_1} = .5278

r_{yx_2} = - .5826

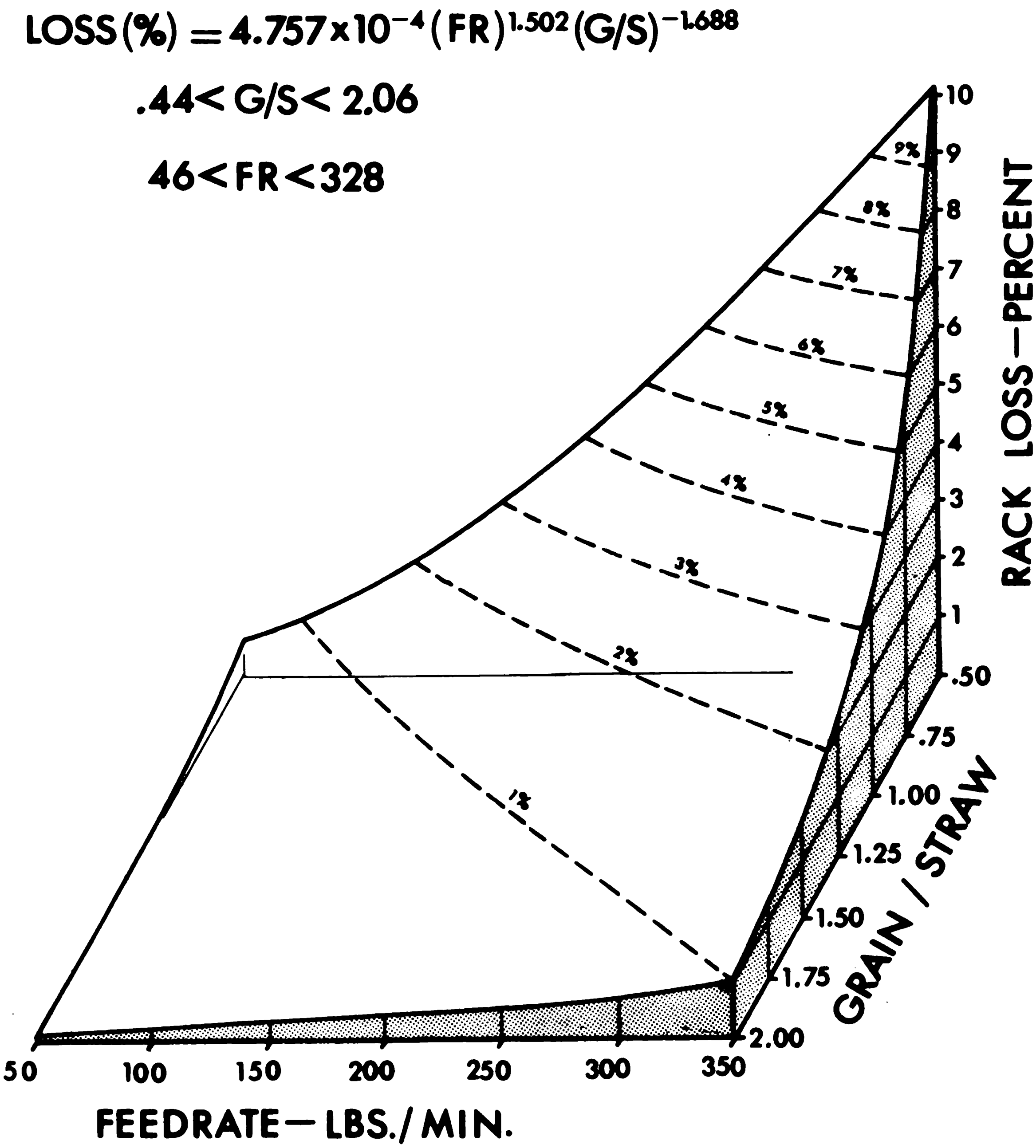
$r_{x_2x_1}$ = - .5809

R = .7092

C = 50.30%

Standard Error of Estimate = .651

The loss surfaces, resulting from these three equations, are shown in Figures 21 to 23. The reasonably good fit of the data for rack loss and shoe loss may be explained as follows: The three varieties of wheat (Thatcher, Canthatch and Selkirk) are quite similar in straw characteristics. The grain moisture content was nearly equal, ranging from 12% to 15%. Hence, it may be concluded that yearly climatic variation had little effect on those

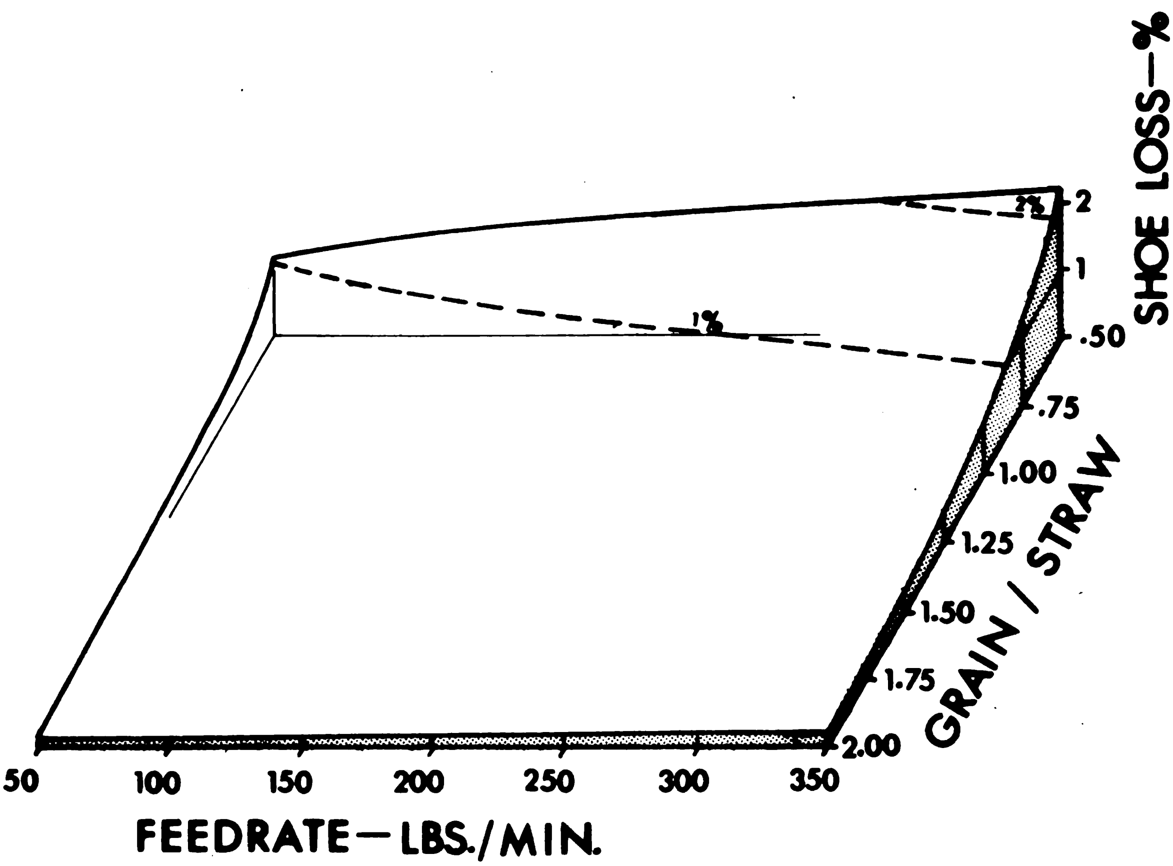


RACK LOSS SURFACE FOR STANDARD COMBINE IN WHEAT
FIGURE 21

$$LOSS(\%) = 1.019 \times 10^{-1}(FR)^{0.320}(G/S)^{-1.734}$$

$$.44 < G/S < 2.06$$

$$46 < FR < 328$$

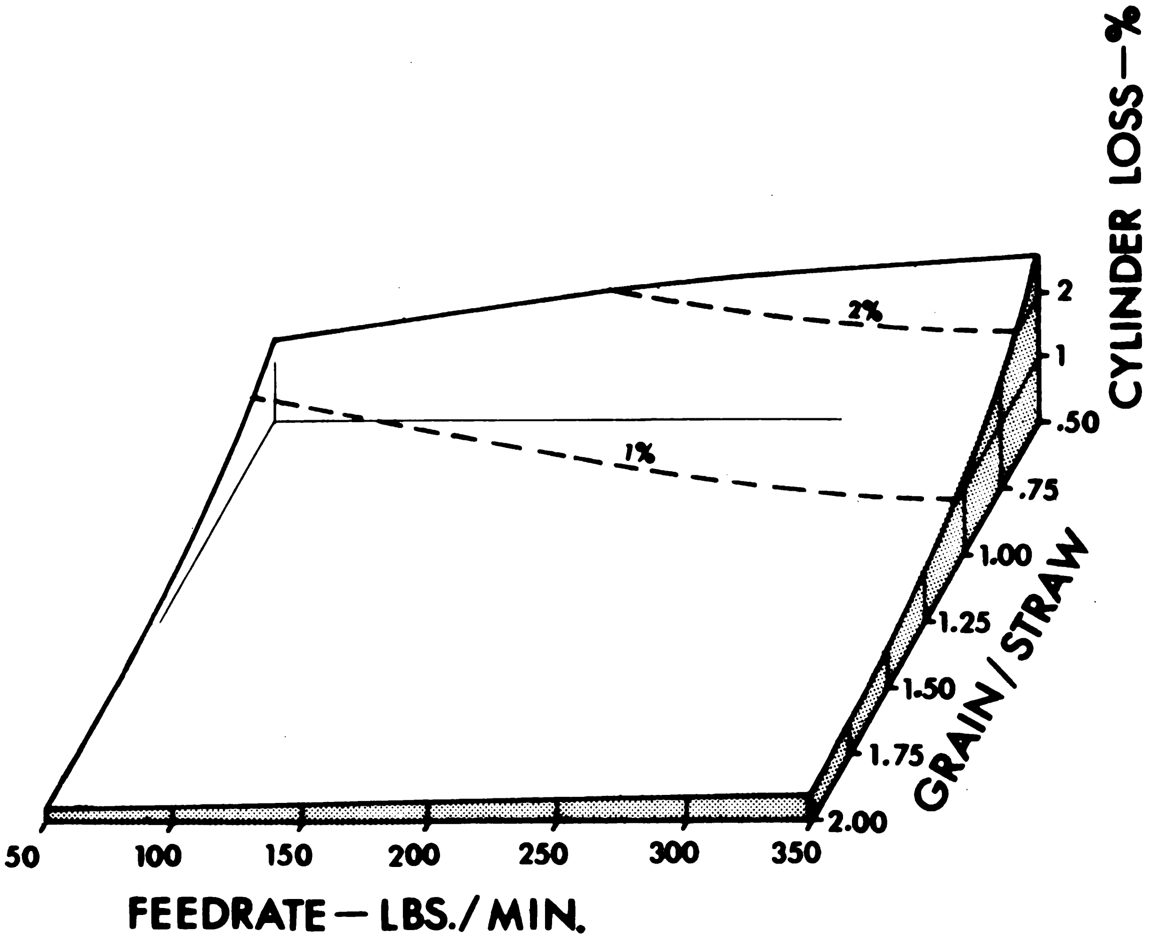


SHOE LOSS SURFACE FOR STANDARD COMBINE IN WHEAT
FIGURE 22

$$LOSS(\%) = 1.159 \times 10^{-1} (FR)^{0.370} (G/S)^{-1.345}$$

$$.44 < G/S < 2.06$$

$$46 < FR < 328$$



CYLINDER LOSS SURFACE FOR STANDARD COMBINE IN WHEAT
FIGURE 23

characteristics of wheat straw influencing straw break-up. The poorer fit for cylinder loss may be explained by the effect of climatic conditions on ease of threshing. The 1963 crops were extremely difficult-to-thresh due to a combination of rust and hot, dry weather at the time of filling, whereas the other wheat crops were relatively easy-to-thresh.

(2) In barley, oats and rye, fitting the loss data as above, yielded poor results. This may be explained by a much greater dependence of straw characteristics on variety, moisture content and growing conditions than in the case of wheat.

In order for the above analysis to produce good fits more crop variables would have to be considered. Probably the inclusion of some variable describing straw strength (straw break-up) would improve the rack loss and shoe loss fits, whereas some variable describing ease of threshing (perhaps straw moisture content) would improve the cylinder loss fits.

Comparison to characteristics of the standard combine

From the above results it is apparent that the use of a standard combine is necessary in comparing the performance of combines tested in different years and conditions, unless additional crop variables are measured.

The following example illustrates how loss data from the standard combine is used in making performance comparisons. Figure 24 gives a comparison between the standard combine and combine "A", in barley, based on loss data collected in 1963.

The best-fit regressions for rack loss are:

standard combine: $RL = 1.478x10^{-3}(FR)^{1.714}\ (G/S)^{1.176}$,

$.87 < G/S < 1.10$

combine "A": $RL = 7.136x10^{-11}\ (FR)^{4.562}(G/S)^{-.953}$,

$.78 < G/S < 1.28$

Basing both equations on a constant grain/ straw ratio of 1.00, the equations become:

standard combine: $RL = 1.478x10^{-3}(FR)^{1.714}$

combine "A": $RL = 7.136x10^{-11}\ (FR)^{4.562}$

These equations, with 95% confidence belts ($\pm$ 2 x $S.E._y$) are shown on Figure 24. At a loss of 3%, the capacity of combine "A" is 2.8 times the capacity of the standard combine.

Figure 25 compares rack loss for the standard combine and machine "B", in barley, based on loss data collected in 1961. The best fit regressions are:

standard combine: $RL = 7.712x10^{-6}\ (FR)^{3.229}\ (G/S)^{-3.161}$,

$1.25 < G/S < 2.48$

combine "B": $RL = 2.060x10^{-15}\ (FR)^{6.473}\ (G/S)^{4.902}$,

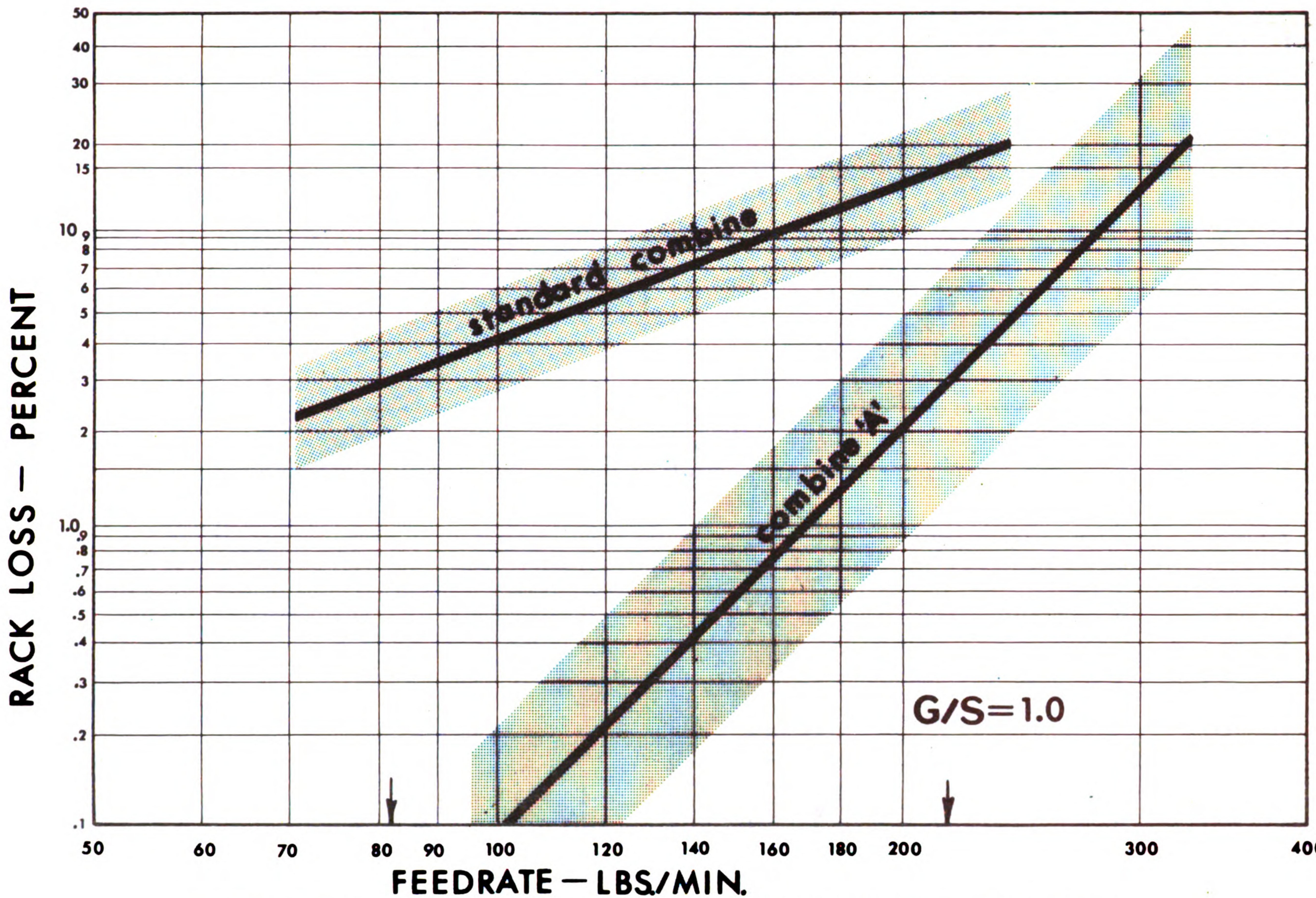
$1.00 < G/S < 2.29$

Basing the above equations on a constant grain/ straw ratio of 2.00, the equations become:

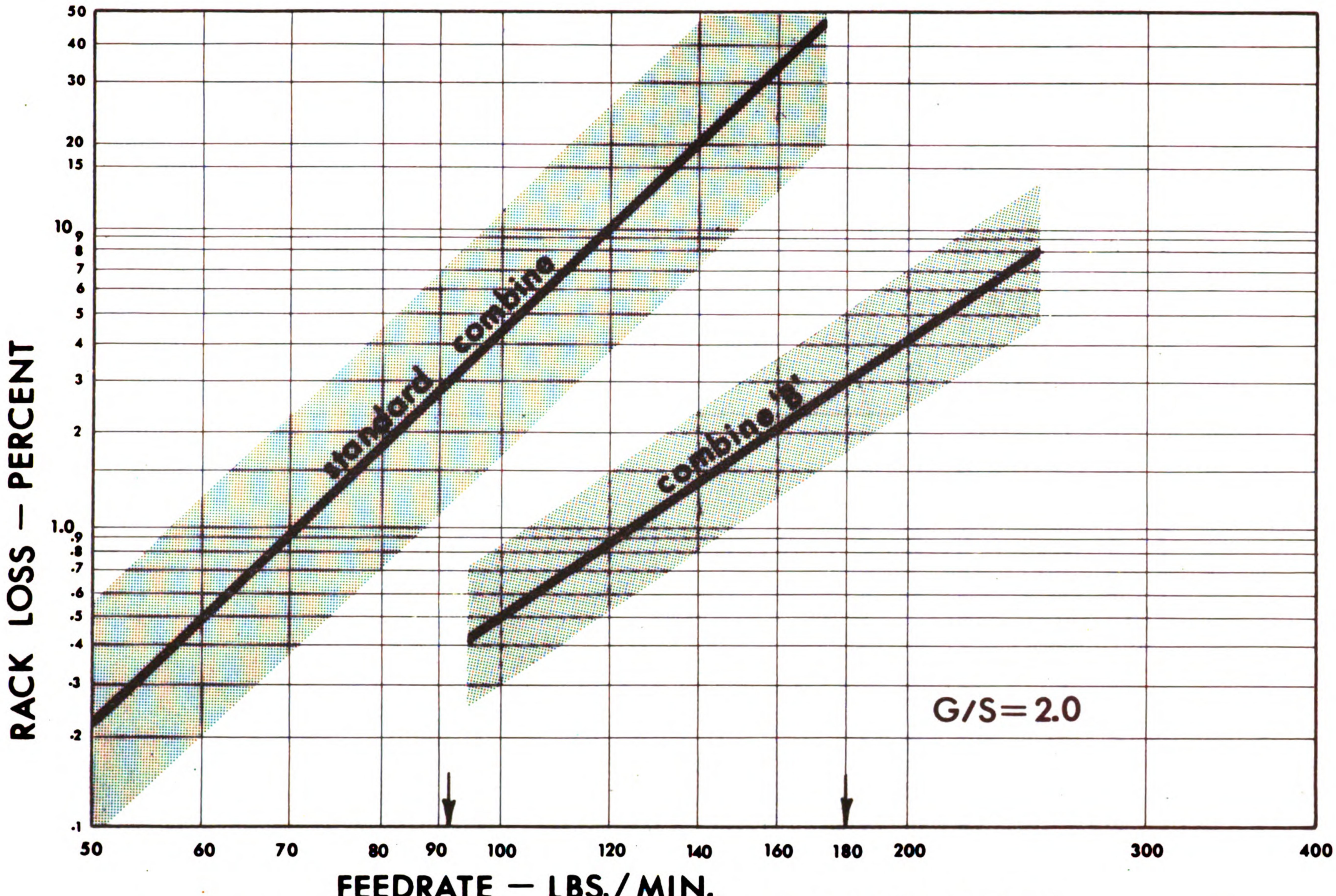
standard combine: $RL = 8.60x10^{-6}\ (FR)^{3.229}$

combine "B": $RL = 6.18x10^{-16}\ (FR)^{6.473}$

These equations, with 95% confidence limits, are shown on Figure 25. At a loss of 3%, the capacity of combine "B" is 2.0 times the capacity of the standard combine.



COMPARISON TO STANDARD COMBINE AT A CONSTANT GRAIN/STRAW RATIO
FIGURE 24



COMPARISON TO STANDARD COMBINE AT A CONSTANT GRAIN/STRAW RATIO
FIGURE 25

Since Figures 24 and 25 are based on different grain/straw ratios and since other unmeasured crop variables may have influenced the results, direct comparison cannot be made between machines "A" and "B". The capacity ratios can, however, be compared to give an estimate. Using the 3% loss comparison ratios from above, the capacity of "A" compared to "B" may be estimated as 2.8/2.0 = 1.4.

* Note: Significant digits in previous regression equations (pages 54, 55 and 60) are retained for purposes of calculation. They are not intended to denote the accuracy of measurements in the experiments.

CONCLUSIONS

1. The multiplicative model, percent loss = a $(\text{feedrate})^b$ $(\text{grain/straw})^c$, provides a good fit for rack loss, shoe loss and cylinder loss data collected in non-uniform fields of varying grain yield and varying straw yield.

2. The exponential model, percent loss = a $(\text{feedrate})^b$, provides a good fit for rack loss, shoe loss and cylinder loss data collected in uniform fields of constant grain/straw ratio.

3. If loss tests are conducted over only a small range of feedrates, a multiple linear model, percent loss = a + b (feedrate) + c (grain/straw), may provide the best fit in non-uniform fields and a simple linear model, percent loss = a + b (feedrate), may provide the best fit in uniform fields.

4. The correlation between percent loss and grain/straw ratio is negative for rack loss, shoe loss and cylinder loss in wheat, oats, barley and rye.

5. The computer program was successful in fitting loss data and comparing models. A computer program for fitting loss data must compare the four models listed above, to obtain the best fit for the conditions involved.

6. The use of feedrate as an independent variable usually gives a better simple fit (neglecting grain/straw variation) than the use of throughput as an independent variable. When grain/straw variation is considered, both parameters give equally good fits.

7. A standard machine is necessary in comparing loss data collected in different years and crop conditions, unless some

measurement is made of straw "break-up" and "ease-of threshing". Best-fit regression equations can be used to allow comparison, between the standard combine and test machines, at a fixed grain/straw ratio and at a selected loss level.

8) In most instances, rack loss was the major component of total machine loss. This suggests that further study should be conducted on the factors affecting rack loss. A theoretical analysis of grain separation on an oscillating rack would be of great value.

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   - Institut Voor Landbouwtechniek en Rationalisatie, Dr. S. L. Mansholtaan 12, Wageningen, Netherlands
   - National Institute of Agricultural Engineering, Wrest Park, Silsoe, Bedfordshire, United Kingdom
   - Profungsabteilung für Landmaschinen, Der Deutschen Landwirtschafts - Gesellschaft, Zimmerweg 16, Frankfurt a. M., Germany
   - Schwiezerisches Institut für Landmaschinenwesen and Landarbeits Technik, Brugg/AG, Switzerland
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APPENDIX I

Fortran Digital Computer Program for Combine Loss Analysis (M.S.U., CDC 3600 Computer)

```
      PROGRAM LOSSCALC
      DIMENSION NRUN(10),WIDTH(10),DISTANCE(10),TIME(10),STRAWAL(10),
     1  CHAFFAL(10),GRAINH(10),RACKL(10),SHOEL(10),DRUML(10),SPEC(10)
      DIMENSION SAC(10),GRAIN(10),FEEDR(10),PLR(10),PLS(10),
     1 PLC(10),SPEED(10),APH(10),GS(10),PGPA(10)  ,GR(54,45,3)
      DIMENSION PLRC(10),PLSC(10),PLCC(10),RER(10),RES(10),REC(10),
     1RLN(10),SLN(10),CLN(10),FLN(10),APR(10),APS(10),APC(10)
      COMMON NRUN,WIDTH,DISTANCE,TIME,STRAWAL,CHAFFAL,GRAINH,RACKL,
     1SHOEL,DRUML,SPEC,SAC,GRAIN,FEEDR,PLR,PLS,PLC,SPEED,APH,GS,PGPA,
     2GR,JM
      COMMON PLRC,PLSC,PLCC,RER,RES,REC,RLN,SLN,CLN,FLN,APR,APS,APC
C     INPUT DATA
C - WIDTH - WIDTH OF CUT (FEET)
C - DISTANCE - LENGTH OF RUN (FEET)
C - TIME - LENGTH OF RUN (MINUTES)
C - STRAWAL - RACK EFFLUENT,STRAW PLUS LOSS (POUNDS)
C - CHAFFAL - SHOE EFFLUENT,CHAFF PLUS LOSS (POUNDS)
C - GRAINH - GRAIN COLLECTED IN HOPPER (POUNDS)
C - RACKL - RACK LOSS (POUNDS)
C - SHOEL - SHOE LOSS (POUNDS)
C - DRUML - CYLINDER LOSS (POUNDS)
C - SPEC - MACHINE AND CROP SPECIFICATIONS
   11 DO 10 J=1,10
      READ 20 ,NRUN(J),WIDTH(J),DISTANCE(J),TIME(J),STRAWAL(J),
     1 CHAFFAL(J),GRAINH(J),RACKL(J),SHOEL(J),DRUML(J)
   20 FORMAT (I2,9F6.2)
   10 CONTINUE
      READ 40,(SPEC(I),I=1,10)
   40 FORMAT (4A6,6A8)
      PRINT 50
   50 FORMAT (*1*5X,9H MACHINE ,9H  MODEL   ,9H   TEST   ,9H SERIES  ,
     1 9H   CROP   ,9H VARIETY ,9H WINDROW ,9H   STRAW  ,9HLOCATION ,
     2 9H   DATE   /24X,9H NUMBER  ,27X,9HOR STAND /)
      PRINT 52,(SPEC(N),N=1,10)
   52 FORMAT (6X,10A9////)
      PRINT 54
   54 FORMAT (6X,9H   RUN   ,9H  WIDTH  ,9H DISTANCE,9H   TIME   ,
     1 9H  STRAW  ,9H  CHAFF  ,9H  GRAIN  ,9H  RACK   ,9H  SHOE   ,
     2 9HCYLINDER ,/42X,9HAND LOSS ,9HAND LOSS ,9HCOLLECTED,
     3 9H  LOSS   ,9H  LOSS   ,9H  LOSS   ,/15X,9H (FEET)  ,9H (FEET)  ,
     4 9H(MINUTES),9H(POUNDS) ,9H(POUNDS) ,9H(POUNDS) ,9H(POUNDS) ,
     5 9H(POUNDS) ,9H(POUNDS) ,/)
      PRINT 56,(NRUN(J),WIDTH(J),DISTANCE(J),TIME(J),STRAWAL(J),
     1 CHAFFAL(J),GRAINH(J),RACKL(J),SHOEL(J),DRUML(J),J=1,10)
   56 FORMAT (9X,I2,1X,9(3X,F6.2))
      CALL CALCULAT
      CALL GRAPH
      CALL FIT
      GO TO 11
      END
```

```
      SUBROUTINE CALCULAT
      DIMENSION NRUN(10),WIDTH(10),DISTANCE(10),TIME(10),STRAWAL(10),
     1  CHAFFAL(10),GRAINH(10),RACKL(10),SHOEL(10),DRUML(10),SPEC(10)
      DIMENSION SAC(10),GRAIN(10),FEEDR(10),PLR(10),PLS(10),
     1 PLC(10),SPEED(10),APH(10),GS(10),PGPA(10)  ,GR(54,45,3)
      DIMENSION PLRC(10),PLSC(10),PLCC(10),RER(10),RES(10),REC(10),
     1RLN(10),SLN(10),CLN(10),FLN(10),APR(10),APS(10),APC(10)
      COMMON NRUN,WIDTH,DISTANCE,TIME,STRAWAL,CHAFFAL,GRAINH,RACKL,
     1SHOEL,DRUML,SPEC,SAC,GRAIN,FEEDR,PLR,PLS,PLC,SPEED,APH,GS,PGPA,
     2GR,JM
      COMMON PLRC,PLSC,PLCC,RER,RES,REC,RLN,SLN,CLN,FLN,APR,APS,APC
      JM=0
      DO 14,J=1,10
      IF(NRUN(J).GT.0) JM=JM+1
   14 CONTINUE
      DO 15 ,J=1,JM
      SAC(J)=STRAWAL(J)-RACKL(J)+CHAFFAL(J)-SHOEL(J)-DRUML(J)
      GRAIN(J)=GRAINH(J)+RACKL(J)+SHOEL(J)+DRUML(J)
      FEEDR(J)=SAC(J)/TIME(J)
      PLR(J)=(RACKL(J)/GRAIN(J))*100.00
      PLS(J)=(SHOEL(J)/GRAIN(J))*100.00
      PLC(J)=(DRUML(J)/GRAIN(J))*100.00
      SPEED(J)=(DISTANCE(J)*60.00)/(5280.00*TIME(J))
      APH(J)=(DISTANCE(J)*WIDTH(J)*60.00)/(43560.00*TIME(J))
      GS(J) = GRAIN(J)/SAC(J)
      PGPA(J)=(GRAIN(J)*43560.00)/(DISTANCE(J)*WIDTH(J))
   15 CONTINUE
C    SAC - STRAW PLUS CHAFF - POUNDS
C    GRAIN - TOTAL GRAIN - POUNDS
C    FEEDR - FEEDRATE - POUNDS PER MINUTE OF STRAW AND CHAFF
C    PLR - RACK LOSS - PERCENT
C    PLS - SHOE LOSS - PERCENT
C    PLC - CYLINDER LOSS - PERCENT
C    SPEED - GROUND SPEED - MILES PER HOUR
C    APH - WORK RATE - ACRES PER HOUR
C    GS - GRAIN TO STRAW RATIO
C    PGPA - GRAIN YIELD - POUNDS PER ACRE
      PRINT 25
   25 FORMAT(*2*,6X,5H  RUN,12H   STRAW AND,9H    TOTAL,12H    FEEDRATE,
     19H     RACK,11H       SHOE,13H     CYLINDER,11H      SPEED,
     213H    WORK RATE,9H    GRAIN,15H    GRAIN/STRAW,/17X,5HCHAFF,
     311H       GRAIN,17X,4HLOSS,7X,4HLOSS,7X,4HLOSS,30X,5HYIELD,6X,
     45HRATIO,/16X,6H(LBS.),6X,6H(LBS.),13H  (LBS./MIN.),10H (PERCENT),
     511H  (PERCENT),11H  (PERCENT),13H  (MILE/HOUR),12H (ACRE/HOUR),
     612H (LBS./ACRE),/)
      PRINT 35,(NRUN(J),SAC(J),GRAIN(J),FEEDR(J),PLR(J),PLS(J),PLC(J),
     1 SPEED(J),APH(J),PGPA(J),GS(J),J=1,JM)
   35 FORMAT(9X,I2,7(3X,F8.2),4X,F8.2,5X,F8.2,1X,F8.2)
      RETURN
      END
```

```
      SUBROUTINE GRAPH
C - GRAPHING PERCENT LOSSES VS FEEDRATE
      DIMENSION NRUN(10),WIDTH(10),DISTANCE(10),TIME(10),STRAWAL(10),
     1  CHAFFAL(10),GRAINH(10),RACKL(10),SHOEL(10),DRUML(10),SPEC(10)
      DIMENSION SAC(10),GRAIN(10),FEEDR(10),PLR(10),PLS(10),
     1 PLC(10),SPEED(10),APH(10),GS(10),PGPA(10)  ,GR(54,45,3)
      DIMENSION PLRC(10),PLSC(10),PLCC(10),RER(10),RES(10),REC(10),
     1RLN(10),SLN(10),CLN(10),FLN(10),APR(10),APS(10),APC(10)
      COMMON NRUN,WIDTH,DISTANCE,TIME,STRAWAL,CHAFFAL,GRAINH,RACKL,
     1SHOEL,DRUML,SPEC,SAC,GRAIN,FEEDR,PLR,PLS,PLC,SPEED,APH,GS,PGPA,
     2GR,JM
      COMMON PLRC,PLSC,PLCC,RER,RES,REC,RLN,SLN,CLN,FLN,APR,APS,APC
      REAL GR,N,L,M,I,NI,NUL
      INTEGER Y,X
      DATA (BLANK=1H ),(DOT=1H.),(PLOT=1H*),(PLUS=1H+)
      DATA (P=1HP),(E=1HE),(R=1HR),(C=1HC),(N=1HN),(T=1HT),(L=1HL),
     1(O=1HO),(S=1HS),(F=1HF),(D=1HD),(A=1HA),(B=1HB),(M=1HM),(I=1HI),
     2(SLASH=1H/),(PARENR=1H)),(PARENL=1H()
      DATA (EN=1H1),(TO=1H2),(TRE=1H3),(FIR=1H4),(FEM=1H5),(SEX=1H6),
     1(SIV=1H7),(OT=1H8),(NI=1H9),(NUL=1H0)
      PRINT 20,(SPEC(NK),NK=1,10)
   20 FORMAT(*1*6X,10A9///)
      PRINT 25
   25 FORMAT(19X,9HRACK LOSS,35X,9HSHOE LOSS,35X,13HCYLINDER LOSS/)
C - FILL GR WITH BLANK
      DO 30 K=1,3
      DO 30 J=1,45
      DO 30 I2=1,54
   30 GR(I2,J,K)=BLANK
C - PLACING HEADINGS AND AXES IN GR
      DO 35 K=1,3
      GR(27,1,K)=P
      GR(28,1,K)=E
      GR(29,1,K)=R
      GR(30,1,K)=C
      GR(31,1,K)=E
      GR(32,1,K)=N
      GR(33,1,K)=T
      GR(35,1,K)=L
      GR(36,1,K)=O
      GR(37,1,K)=S
      GR(38,1,K)=S
   35 CONTINUE
      DO 37 K=1,3
      DO 36 I2=2,10,2
   36 GR(I2,3,K)=TO
   37 CONTINUE
      DO 38 K=1,3
      DO 33 I2=12,30,2
   33 GR(I2,3,K)=EN
   38 CONTINUE
      DO 39 K=1,3
      GR(2,4,K)=FIR
      GR(4,4,K)=TRE
      GR(6,4,K)=TO
      GR(8,4,K)=EN
```

```
      GR(10,4,K)=NUL
      GR(12,4,K)=NI
      GR(14,4,K)=OT
      GR(16,4,K)=SIV
      GR(18,4,K)=SEX
      GR(20,4,K)=FEM
      GR(22,4,K)=FIR
      GR(24,4,K)=TRE
      GR(26,4,K)=TO
      GR(28,4,K)=EN
      GR(30,4,K)=NUL
      GR(32,4,K)=NI
      GR(34,4,K)=OT
      GR(36,4,K)=SIV
      GR(38,4,K)=SEX
      GR(40,4,K)=FEM
      GR(42,4,K)=FIR
      GR(44,4,K)=TRE
      GR(46,4,K)=TO
      GR(48,4,K)=EN
      GR(50,4,K)=NUL
   39 CONTINUE
      DO 41 K=1,3
      DO 40 I2=1,50
   40 GR(I2,6,K)=DOT
   41 CONTINUE
      DO 43 K=1,3
      DO 42 J=7,45
   42 GR(50,J,K)=DOT
   43 CONTINUE
      DO 45 K=1,3
      GR(52,6,K)=NUL
      GR(52,15,K)=EN
      GR(52,16,K)=NUL
      GR(52,17,K)=NUL
      GR(52,25,K)=TO
      GR(52,26,K)=NUL
      GR(52,27,K)=NUL
      GR(52,35,K)=TRE
      GR(52,36,K)=NUL
      GR(52,37,K)=NUL
      GR(54,14,K)=F
      GR(54,15,K)=E
      GR(54,16,K)=E
      GR(54,17,K)=D
      GR(54,18,K)=R
      GR(54,19,K)=A
      GR(54,20,K)=T
      GR(54,21,K)=E
      GR(54,23,K)=PARENL
      GR(54,24,K)=L
      GR(54,25,K)=B
      GR(54,26,K)=S
      GR(54,27,K)=DOT
      GR(54,28,K)=SLASH
      GR(54,29,K)=M
```

```
      GR(54,30,K)=I
      GR(54,31,K)=N
      GR(54,32,K)=DOT
      GR(54,33,K)=PARENR
   45 CONTINUE
C - ENTERING PLOT IN RACK GR
      DO 50 J=1,JM
      KP=0
      KF=0
      Y=PLR(J)/0.5
      IF (PLR(J)/0.5-0.5.GT.Y)  Y=Y+1
      II=50-Y
      IF(II.LT.1) GO TO 70
      GO TO 71
   70 II=1
      KP = 1
   71 X=FEEDR(J)/10.0
      IF (FEEDR(J).GT.X*10+5)  X=X+1
      MN=X+6
      IF(MN.GT.45) GO TO 72
      GO TO 73
   72 MN=45
      KF = 1
   73 IF(KP.EQ.1.OR.KF.EQ.1) GO TO 74
      GO TO 75
   74 GR(II,MN,1)=PLUS
      GO TO 50
   75 GR(II,MN,1)=PLOT
   50 CONTINUE
C - ENTERING PLOT IN SHOE GR
      DO 51 J=1,JM
      KP=0
      KF=0
      Y=PLS(J)/0.5
      IF(PLS(J)/0.5-0.5.GT.Y)  Y=Y+1
      II=50-Y
      IF(II.LT.1) GO TO 80
      GO TO 81
   80 II=1
      KP=1
   81 X=FEEDR(J)/10.0
      IF(FEEDR(J).GT.X*10+5)  X=X+1
      MN=X+6
      IF(MN.GT.45) GO TO 82
      GO TO 83
   82 MN=45
      KF=1
   83 IF(KP.EQ.1.OR.KF.EQ.1) GO TO 84
      GO TO 85
   84 GR(II,MN,2) = PLUS
      GO TO 51
   85 GR(II,MN,2) = PLOT
   51 CONTINUE
C - ENTERING PLOT IN CYLINDER GR
      DO 52 J=1,JM
      KP=0
```

```
      KF=0
      Y=PLC(J)/0.5
      IF(PLC(J)/0.5-0.5.GT.Y)  Y=Y+1
      II=50-Y
      IF(II.LT.1) GO TO 90
      GO TO 91
   90 II=1
      KP=1
   91 X=FEEDR(J)/10.0
      IF(FEEDR(J).GT.X*10+5)  X=X+1
      MN=X+6
      IF(MN.GT.45) GO TO 92
      GO TO 93
   92 MN=45
      KF=1
   93 IF(KP.EQ.1.OR.KF.EQ.1) GO TO 94
      GO TO 95
   94 GR(II,MN,3) = PLUS
      GO TO 52
   95 GR(II,MN,3) = PLOT
   52 CONTINUE
      DO 65 IN=1,54
      PRINT 60,(GR(IN,J,1),J=1,45),(GR(IN,J,2),J=1,45),
     1(GR(IN,J,3),J=1,45)
   60 FORMAT (1H ,45A1,45A1,45A1)
   65 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE FIT
      DIMENSION NRUN(10),WIDTH(10),DISTANCE(10),TIME(10),STRAWAL(10),
     1  CHAFFAL(10),GRAINH(10),RACKL(10),SHOEL(10),DRUML(10),SPEC(10)
      DIMENSION SAC(10),GRAIN(10),FEEDR(10),PLR(10),PLS(10),
     1 PLC(10),SPEED(10),APH(10),GS(10),PGPA(10)  ,GR(54,45,3)
      DIMENSION FTAB(10,2),TTAB(10),KSIG(4),PLRC(10),PLSC(10),PLCC(10),
     1RER(10),RES(10),REC(10),RLN(10),SLN(10),CLN(10),FLN(10),APR(10),
     2APS(10),APC(10)
      DIMENSION GRR(19,45,3)
      DIMENSION GLN(10),G11(10),G12(10),RER1(10),RER2(10),RES1(10),
     1RES2(10),REC1(10),REC2(10)
      COMMON NRUN,WIDTH,DISTANCE,TIME,STRAWAL,CHAFFAL,GRAINH,RACKL,
     1SHOEL,DRUML,SPEC,SAC,GRAIN,FEEDR,PLR,PLS,PLC,SPEED,APH,GS,PGPA,
     2GR,JM
      COMMON PLRC,PLSC,PLCC,RER,RES,REC,RLN,SLN,CLN,FLN,APR,APS,APC
      REAL GRR,I,L,NUL
C   SIMPLE CORRELATION
C   GRAIN/STRAW VARIATION NEGLECTED
C   STORING F-DISTRIBUTION TABLE
C   FIRST COLUMN OF FTAB STORES 5PERCENT F(UPPER CUT OFF POINT)
C   SECOND COLUMN OF FTAB STORES 2.5PERCENT F (UPPER CUT OFF POINT)
C   DEGREES OF FREEDOM IN NUMERATOR = 1
C   DEGREES OF FREEDOM IN DENOMINATOR = ARRAY ROW
      DATA(FTAB=161.45,18.513,10.128,7.7086,6.6079,5.9874,5.5914,
     1 5.3177,5.1174,4.9646,647.79,38.506,17.443,12.218,10.007,8.8131,
     2 8.0727,7.5709,7.2093,6.9367)
      DATA(KSIG=8HSIGNIFIC,7HANT    ,8HNOT SIGN,7HIFICANT)
C   STORING 5PERCENT T-DISTRIBUTION TABLE
C   DEGREES OF FREEDOM = ARRAY ROW
      DATA(TTAB = 6.314,2.920,2.353,2.132,2.015,1.943,1.895,1.860,
     1 1.833,1.812)
      DATA (BLANK=1H ),(DOT=1H.),(PLOT=1H*),(PLUS=1H+),(DA=1H-),(X=1HX),
     1(R=1HR),(E=1HE),(S=1HS),(I=1HI),(D=1HD),(U=1HU),(A=1HA),(L=1HL),
     2(F=1HF),(T=1HT),(EN=1H1),(TO=1H2),(TRE=1H3),(FIR=1H4),(NUL=1H0)
      LR = 0
      NOE=0
  200 LR = LR+1
      YR=0
      YR2=0
      YS=0
      YS2=0
      YC=0
      YC2=0
      XI=0
      XI2=0
      XIYR=0
      XIYS=0
      XIYC=0
      JM=0
      DO8,J=1,10
      IF(NRUN(J).GT.0) JM=JM+1
    8 CONTINUE
      EE=JM
      DO9,J=1,JM
      IF(PLR(J).EQ.0) PLR(J)=0.01
      IF(PLS(J).EQ.0) PLS(J)=0.01
```

```
      IF(PLC(J).EQ.0) PLC(J)=0.01
    9 CONTINUE
C   REGRESSING LOSSES ON FEEDRATE
      IF(LR-2) 150,151,152
  150 DO 10,J=1,JM
      YR=YR+PLR(J)
      YRL=YR
      YR2=YR2+PLR(J)**2
      YS=YS+PLS(J)
      YSL=YS
      YS2=YS2+PLS(J)**2
      YC=YC+PLC(J)
      YCL=YC
      YC2=YC2+PLC(J)**2
      XIYR=XIYR+PLR(J)*FEEDR(J)
      XIYS=XIYS+PLS(J)*FEEDR(J)
      XIYC=XIYC+PLC(J)*FEEDR(J)
      XI=XI+FEEDR(J)
   10 XI2=XI2+FEEDR(J)**2
      GO TO 160
  151 DO161,J=1,JM
      RLN(J)=LOGF(PLR(J))
      SLN(J)=LOGF(PLS(J))
      CLN(J)=LOGF(PLC(J))
      FLN(J)=LOGF(FEEDR(J))
      YR=YR+RLN(J)
      YRE=YR
      YR2=YR2+RLN(J)**2
      YS=YS+SLN(J)
      YSE=YS
      YS2=YS2+SLN(J)**2
      YC=YC+CLN(J)
      YCE=YC
      YC2=YC2+CLN(J)**2
      XIYR=XIYR+RLN(J)*FLN(J)
      XIYS=XIYS+SLN(J)*FLN(J)
      XIYC=XIYC+CLN(J)*FLN(J)
      XI=XI+FLN(J)
  161 XI2=XI2+FLN(J)**2
      GO TO 160
  152 DO 162,J=1,JM
      YR=YR+RLN(J)
      YR2=YR2+RLN(J)**2
      YS=YS+SLN(J)
      YS2=YS2+SLN(J)**2
      YC=YC+CLN(J)
      YC2=YC2+CLN(J)**2
      XIYR=XIYR+RLN(J)*FEEDR(J)
      XIYS=XIYS+SLN(J)*FEEDR(J)
      XIYC=XIYC+CLN(J)*FEEDR(J)
      XI=XI+FEEDR(J)
  162 XI2=XI2+FEEDR(J)**2
  160 SX2=XI2-(XI**2)/EE
      SYR2=YR2-(YR**2)/EE
      SYS2=YS2-(YS**2)/EE
      SYC2=YC2-(YC**2)/EE
```

```
      SXYR=XIYR-(XI*YR)/EE
      SXYS=XIYS-(XI*YS)/EE
      SXYC=XIYC-(XI*YC)/EE
      IF(LR-2)950,951,952
  950 SYR2L=SYR2
      SYS2L=SYS2
      SYC2L=SYC2
      GO TO 952
  951 SYR2E=SYR2
      SYS2E=SYS2
      SYC2E=SYC2
C   COMPUTING THE CORRELATION COEFFICIENT,R
  952 RR2=(SXYR **2)/(SX2*SYR2)
      CR=RR2*100.0
      IF(SXYR.LT.0)900,901
  900 RR=-1.0*SQRT(RR2)
      GO TO 902
  901 RR=SQRT(RR2)
  902 RS2=(SXYS **2)/(SX2*SYS2)
      CS=RS2*100.0
      IF(SXYS.LT.0)903,904
  903 RS=-1.0*SQRT(RS2)
      GO TO 905
  904 RS=SQRT(RS2)
  905 IF(SXYC.EQ.0)1361,1362
 1361 RC2=0.0
      RC=0.0
      CC=0.0
      GO TO 908
 1362 RC2=(SXYC **2)/(SX2*SYC2)
      CC=RC2*100.0
      IF(SXYC.LT.0)906,907
  906 RC=-1.0*SQRT(RC2)
      GO TO 908
  907 RC=SQRT(RC2)
C   COMPUTING THE SLOPE,B
  908 BR=SXYR /SX2
      BS=SXYS /SX2
      BC=SXYC /SX2
      IF(LR-2)960,961,962
  960 RR2L=RR2
      RRL=RR
      RS2L=RS2
      RSL=RS
      RC2L=RC2
      RCL=RC
      GO TO 962
  961 RR2E=RR2
      RRE=RR
      RS2E=RS2
      RSE=RS
      RC2E=RC2
      RCE=RC
C   COMPUTING THE Y-INTERCEPT,A
  962 XB=XI/EE
      YBR=YR/EE
```

```
      YBS=YS/EE
      YBC=YC/EE
      AR=YBR-BR*XB
      AS=YBS-BS*XB
      AC=YBC-BC*XB
      IF(LR-2)920,921,922
  920 AR10=AR
      AS10=AS
      AC10=AC
      BR10=BR
      BS10=BS
      BC10=BC
      GO TO 922
  921 AR20=AR
      AS20=AS
      AC20=AC
      BR20=BR
      BS20=BS
      BC20=BC
C   ANOVA
C   SSR = SUM OF SQUARES,REGRESSION
C   SSDR = SUM OF SQUARES,DEVIATION FROM REGRESSION
  922 SSRR=RR2*SYR2
      SSRS=RS2*SYS2
      SSRC=RC2*SYC2
      SSDRR=(1.0-RR2)*SYR2
      SSDRS=(1.0-RS2)*SYS2
      SSDRC=(1.0-RC2)*SYC2
C   MEAN SQUARE
      DMSR=SSDRR/(EE-2.0)
      DMSS=SSDRS/(EE-2.0)
      DMSC=SSDRC/(EE-2.0)
C   COMPUTING F (ONE TAILED F TEST)
      FR=SSRR/DMSR
      FS=SSRS/DMSS
      IF(SSRC.EQ.0)1363,1364
 1363 FC=0.0
      GO TO 1365
 1364 FC=SSRC/DMSC
C   CHECK FOR SIGNIFICANCE
 1365 IF(FR.GT.FTAB((JM-2),2))90,91
   90 MR2=1
      GO TO 92
   91 MR2=3
   92 IF(FR.GT.FTAB((JM-2),1))93,94
   93 MR5=1
      GO TO 95
   94 MR5=3
   95 IF(FS.GT.FTAB((JM-2),2))96,97
   96 MS2=1
      GO TO 98
   97 MS2=3
   98 IF(FS.GT.FTAB((JM-2),1))99,100
   99 MS5=1
      GO TO 101
  100 MS5=3
```

```
101 IF(FC.GT.FTAB((JM-2),2))102,103
102 MC2=1
    GO TO 104
103 MC2=3
104 IF(FC.GT.FTAB((JM-2),1))105,106
105 MC5=1
    GO TO 107
106 MC5=3
107 IF(LR-2)110,111,112
110 GO TO 108
111 AR1=EXP(AR)
    AS1=EXP(AS)
    AC1=EXP(AC)
    GO TO 108
112 AR2=EXP(AR)
    AS2=EXP(AS)
    AC2=EXP(AC)
    BR2=EXP(BR)
    BS2=EXP(BS)
    BC2=EXP(BC)
108 PRINT 20,(SPEC(NK),NK=1,10)
 20 FORMAT(*1*15X,10A9/)
    IF(LR-2)21,22,23
 21 PRINT31
 31 FORMAT (51X,34HFITTING A LINEAR FUNCTION , Y=A+BX/)
    GO TO40
 22 PRINT 32
 32 FORMAT(45X,46HFITTING AN EXPONENTIAL FUNCTION , Y=A(X)EXP(B)/)
    GO TO 40
 23 PRINT 33
 33 FORMAT(43X,52HFITTING A SIMPLE EXPONENTIAL FUNCTION , Y=A(B)EXP(X)
   1/)
 40 PRINT 41
 41 FORMAT(19X,9HRACK LOSS,35X,9HSHOE LOSS,35X,13HCYLINDER LOSS/)
    IF(LR-2)51,52,53
 51 PRINT 61,(AR,BR,AS,BS,AC,BC)
 61 FORMAT(1X,13HPERCENT LOSS=,E10.3,1H+,E10.3,6H(FEED),5X,
   113HPERCENT LOSS=,E10.3,1H+,E10.3,6H(FEED),5X,
   213HPERCENT LOSS=,E10.3,1H+,E10.3,6H(FEED),/)
    GO TO 70
 52 PRINT 62,(AR1,BR,AS1,BS,AC1,BC)
 62 FORMAT(1X,13HPERCENT LOSS=,E10.3,13H(FEEDRATE)EXP,F6.3,
   13X,13HPERCENT LOSS=,E10.3,13H(FEEDRATE)EXP,F6.3,
   23X,13HPERCENT LOSS=,E10.3,13H(FEEDRATE)EXP,F6.3/)
    GO TO 70
 53 PRINT 63,(AR2,BR2,AS2,BS2,AC2,BC2)
 63 FORMAT(1X,10HPERC LOSS=,E10.3,1H(,E10.3,11H)EXP(FEED ),
   13X,10HPERC LOSS=,E10.3,1H(,E10.3,11H)EXP(FEED ),
   23X,10HPERC LOSS=,E10.3,1H(,E10.3,11H)EXP(FEED )/)
 70 PRINT 71
 71 FORMAT(1X,39H FEEDRATE  MEASURED CALCULATED RESIDUAL,6X,
   139H FEEDRATE  MEASURED CALCULATED RESIDUAL,6X,
   239H FEEDRATE  MEASURED CALCULATED RESIDUAL,/14X,4HLOSS,6X,4HLOSS,
   331X,4HLOSS,6X,4HLOSS,31X,4HLOSS,6X,4HLOSS/)
    IF(LR-2)73,74,75
 73 DO 76,J=1,JM
```

```
      PLRC(J)=AR+BR*FEEDR(J)
      PLSC(J)=AS+BS*FEEDR(J)
   76 PLCC(J)=AC+BC*FEEDR(J)
      GO TO 120
   74 DO 77,J=1,JM
      PLRC(J)=AR1*((FEEDR(J))**BR)
      PLSC(J)=AS1*((FEEDR(J))**BS)
   77 PLCC(J)=AC1*((FEEDR(J))**BC)
      GO TO 120
   75 DO 78,J=1,JM
      PLRC(J)=AR2*(BR2**FEEDR(J))
      PLSC(J)=AS2*(BS2**FEEDR(J))
   78 PLCC(J)=AC2*(BC2**FEEDR(J))
C  RER - RESIDUAL,Y-POINT MINUS Y-LINE , RACK LOSS
C  RES - RESIDUAL,Y-POINT MINUS Y-LINE , SHOE LOSS
C  REC - RESIDUAL,Y-POINT MINUS Y-LINE , CYLINDER LOSS
  120 IF(LR-2) 701,702,703
  701 DO 444,J=1,JM
      RER(J)=PLR(J)-PLRC(J)
      RES(J)=PLS(J)-PLSC(J)
      REC(J)=PLC(J)-PLCC(J)
      RER1(J)=RER(J)
      RES1(J)=RES(J)
  444 REC1(J)=REC(J)
      GO TO 704
  702 DO 705,J=1,JM
      RER(J)=RLN(J)-(AR+BR*FLN(J))
      RES(J)=SLN(J)-(AS+BS*FLN(J))
      REC(J)=CLN(J)-(AC+BC*FLN(J))
      RER2(J)=RER(J)
      RES2(J)=RES(J)
  705 REC2(J)=REC(J)
      GO TO 704
  703 DO 706,J=1,JM
      RER(J)=RLN(J)-(AR+BR*FEEDR(J))
      RES(J)=SLN(J)-(AS+BS*FEEDR(J))
  706 REC(J)=CLN(J)-(AC+BC*FEEDR(J))
C  FINDING STANDARD ERROR OF THE ESTIMATE
  704 RERQ=0
      RESQ=0
      RECQ=0
      DO 707 J=1,JM
      RERQ=RERQ+RER(J)**2
      RESQ=RESQ+RES(J)**2
  707 RECQ=RECQ+REC(J)**2
      SER2=RERQ/(EE-2.0)
      SES2=RESQ/(EE-2.0)
      SEC2=RECQ/(EE-2.0)
      SER=SQRT(SER2)
      SES=SQRT(SES2)
      IF(SEC2.EQ.0)1370,1371
 1370 SEC=0.0
      GO TO 4000
 1371 SEC=SQRT(SEC2)
C  PLACING HEADINGS AND AXES IN GRR
 4000 DO 402 K=1,3
```

```
      DO 402 J=1,45
      DO 402 II=1,19
  402 GRR(II,J,K)=BLANK
      DO 400 K=1,3
      DO 400 J=4,45
  400 GRR(3,J,K)=DOT
      DO 401 K=1,3
      DO 401 II=4,19
      GRR(II,4,K)=DOT
  401 GRR(II,25,K)=DOT
      DO 403 K=1,3
      GRR(1,21,K)=R
      GRR(1,22,K)=E
      GRR(1,23,K)=S
      GRR(1,24,K)=I
      GRR(1,25,K)=D
      GRR(1,26,K)=U
      GRR(1,27,K)=A
  403 GRR(1,28,K)=L
      DO 404 K=1,3
      GRR(2,4,K)=DA
      GRR(2,5,K)=TO
      GRR(2,14,K)=DA
      GRR(2,15,K)=EN
      GRR(2,25,K)=NUL
      GRR(2,34,K)=PLUS
      GRR(2,35,K)=EN
      GRR(2,44,K)=PLUS
  404 GRR(2,45,K)=TO
      DO 405 K=1,3
      GRR(3,3,K)=NUL
      GRR(7,3,K)=EN
      GRR(11,3,K)=TO
      GRR(15,3,K)=TRE
  405 GRR(19,3,K)=FIR
      DO 406 K=1,3
      GRR(5,1,K)=F
      GRR(6,1,K)=E
      GRR(7,1,K)=E
      GRR(8,1,K)=D
      GRR(9,1,K)=R
      GRR(10,1,K)=A
      GRR(11,1,K)=T
      GRR(12,1,K)=E
      GRR(14,1,K)=X
      GRR(15,1,K)=EN
      GRR(16,1,K)=NUL
  406 GRR(17,1,K)=NUL
C   PLOTTING RACK RESIDUALS
      DO 1406 J=1,JM
      KP=0
      NX=RER(J)/0.1
      IF(NX.GT.0)407,408
  407 IF(RER(J)/0.1-0.1.GT.NX) NX=NX+1
      IF(NX.GT.20) GO TO 409
      GO TO 410
```

```
  409 NX=20
      KP=1
      GO TO 410
  408 IF(RER(J)/0.1+0.1.LT.NX) NX=NX-1
      IF(NX.LT.-20) GO TO 411
      GO TO 410
  411 NX=-20
      KP=1
  410 JJ=25+NX
      NY=FEEDR(J)/25.0
      IF(FEEDR(J).GT.NY*25+12) NY=NY+1
      II=NY+3
      IF(II.GT.19) II=19
      IF(KP.EQ.1)GO TO 412
      GO TO 413
  412 GRR(II,JJ,1)=X
      GO TO 1406
  413 GRR(II,JJ,1)=PLOT
 1406 CONTINUE
C   PLOTTING SHOE RESIDUALS
      DO 416 J=1,JM
      KP=0
      NX=RES(J)/0.1
      IF(NX.GT.0)417,418
  417 IF(RES(J)/0.1-0.1.GT.NX) NX=NX+1
      IF(NX.GT.20) GO TO 419
      GO TO 420
  419 NX=20
      KP=1
      GO TO 420
  418 IF(RES(J)/0.1+0.1.LT.NX) NX=NX-1
      IF(NX.LT.-20) GO TO 421
      GO TO 420
  421 NX=-20
      KP=1
  420 JJ=25+NX
      NY=FEEDR(J)/25.0
      IF(FEEDR(J).GT.NY*25+12) NY=NY+1
      II=NY+3
      IF(II.GT.19) II=19
      IF(KP.EQ.1) GO TO 422
      GO TO 423
  422 GRR(II,JJ,2)=X
      GO TO 416
  423 GRR(II,JJ,2)=PLOT
  416 CONTINUE
C   PLOTTING CYLINDER RESIDUALS
      DO 426 J=1,JM
      KP=0
      NX=REC(J)/0.1
      IF(NX.GT.0)427,428
  427 IF(REC(J)/0.1-0.1.GT.NX) NX=NX+1
      IF(NX.GT.20) GO TO 429
      GO TO 430
  429 NX=20
      KP=1
```

```
      GO TO 430
  428 IF(REC(J)/0.1+0.1.LT.NX) NX=NX-1
      IF(NX.LT.-20) GO TO 431
      GO TO 430
  431 NX=-20
      KP=1
  430 JJ=25+NX
      NY=FEEDR(J)/25.0
      IF(FEEDR(J).GT.NY*25+12) NY=NY+1
      II=NY+3
      IF(II.GT.19) II=19
      IF(KP.EQ.1) GO TO 432
      GO TO 433
  432 GRR(II,JJ,3)=X
      GO TO 426
  433 GRR(II,JJ,3)=PLOT
  426 CONTINUE
      IF(NOE-1)5000,884,856
 5000 PRINT 121,(FEEDR(J),PLR(J),PLRC(J),RER(J),FEEDR(J),PLS(J),PLSC(J),
     1RES(J),FEEDR(J),PLC(J),PLCC(J),REC(J),J=1,JM)
  121 FORMAT(*+*,2X,F6.2,5X,F5.2,5X,F5.2,4X,F7.3,8X,F6.2,5X,F5.2,5X,
     1F5.2,4X,F7.3,8X,F6.2,5X,F5.2,5X,F5.2,4X,F7.3/)
      PRINT 122,(RR,RS,RC)
  122 FORMAT(     2X,35HCOEFFICIENT OF LINEAR CORRELATION =,F7.4,4X,
     135HCOEFFICIENT OF LINEAR CORRELATION =,F7.4,4X,
     235HCOEFFICIENT OF LINEAR CORRELATION =,F7.4,/)
      PRINT 499,(CR,CS,CC)
  499 FORMAT(*+*,2X,29HCOEFFICIENT OF DETERMINATION=,F5.2,7HPERCENT,5X,
     129HCOEFFICIENT OF DETERMINATION=,F5.2,7HPERCENT,5X,
     229HCOEFFICIENT OF DETERMINATION=,F5.2,7HPERCENT,/)
      PRINT 123
  123 FORMAT(*+*,40H F(CALC) F(2.5PCENT)  F(CALC)  F(5PCENT),6X,
     140H F(CALC) F(2.5PCENT)  F(CALC)  F(5PCENT),6X,
     240H F(CALC) F(2.5PCENT)  F(CALC)  F(5PCENT)/)
      PRINT 124,(FR,FTAB((JM-2),2),FR,FTAB((JM-2),1),FS,FTAB((JM-2),2),
     1FS,FTAB((JM-2),1),FC,FTAB((JM-2),2),FC,FTAB((JM-2),1))
  124 FORMAT (*+*,F8.4,2X,F8.4,3X,F8.4,2X,F8.4,5X,F8.4,2X,F8.4,3X,F8.4,
     12X,F8.4,5X,F8.4,2X,F8.4,3X,F8.4,2X,F8.4/)
      PRINT 125,(KSIG(MR2),KSIG(MR2+1),KSIG(MR5),KSIG(MR5+1),KSIG(MS2),
     1KSIG(MS2+1),KSIG(MS5),KSIG(MS5+1),KSIG(MC2),KSIG(MC2+1),KSIG(MC5),
     2KSIG(MC5+1))
  125 FORMAT (*+*,3X,A8,A7,5X,A8,A7,10X,A8,A7,5X,A8,A7,10X,A8,A7,5X,
     1A8,A7/)
C FINDING THE LIMITS OF PREDICTION
C  TWO-TAILED T TEST
C   (N-2) DEGREES OF FREEDOM
C   90 PERCENT CONFIDENCE LEVEL
      IF(LR-2) 300,301,300
  300 DO 311,J=1,JM
      APR(J)=TTAB(JM-2)*SER*SQRT(1.0+(1.0/EE)+((FEEDR(J)-XB)**2)/
     1(XI2-EE*(XB**2)))
      APS(J)=TTAB(JM-2)*SES*SQRT(1.0+(1.0/EE)+((FEEDR(J)-XB)**2)/
     1(XI2-EE*(XB**2)))
  311 APC(J)=TTAB(JM-2)*SEC*SQRT(1.0+(1.0/EE)+((FEEDR(J)-XB)**2)/
     1(XI2-EE*(XB**2)))
      GO TO 500
```

```
  301 DO 321,J=1,JM
      APR(J)=TTAB(JM-2)*SER*SQRT(1.0+(1.0/EE)+((FLN(J)   -XB)**2)/
     1(XI2-EE*(XB**2)))
      APS(J)=TTAB(JM-2)*SES*SQRT(1.0+(1.0/EE)+((FLN(J)   -XB)**2)/
     1(XI2-EE*(XB**2)))
  321 APC(J)=TTAB(JM-2)*SEC*SQRT(1.0+(1.0/EE)+((FLN(J)   -XB)**2)/
     1(XI2-EE*(XB**2)))
  500 PRINT 312,(SER,SES,SEC)
  312 FORMAT(*+*,33HSTANDARD ERROR OF THE ESTIMATE = ,F6.3,7X,
     133HSTANDARD ERROR OF THE ESTIMATE = ,F6.3,7X,
     233HSTANDARD ERROR OF THE ESTIMATE = ,F6.3//)
      PRINT 313
  313 FORMAT(*+*,58X,20HLIMITS OF PREDICTION//)
      PRINT 314
  314 FORMAT(*+*,10X,8HFEEDRATE,7X,1HA,32X,8HFEEDRATE,7X,1HA,32X,
     18HFEEDRATE,7X,1HA/)
      PRINT 315,(FEEDR(J),APR(J),FEEDR(J),APS(J),FEEDR(J),APC(J),J=1,JM)
  315 FORMAT(*+*,11X,F6.2,5X,F6.2,31X,F6.2,5X,F6.2,31X,F6.2,5X,F6.2/)
      DO 440 IN=1,19
      PRINT 441,(GRR(IN,J,1),J=1,45),(GRR(IN,J,2),J=1,45),
     1 (GRR(IN,J,3),J=1,45)
  441 FORMAT (*+*,45A1,45A1,45A1/)
  440 CONTINUE
      IF (LR.LT.3) GO TO 200
C  MULTIPLE REGRESSION AS A SEQUENCE OF STRAIGHT LINE REGRESSIONS
      PRINT 20,(SPEC(NK),NK=1,10)
      DO 800 J=1,JM
  800 GLN(J)=LOGF(GS(J))
      PRINT 811
  811 FORMAT(50X,34HREGRESSING GRAIN/STRAW ON FEEDRATE/)
  801 LR=LR+1
      GI=0
      GI2=0
      GIX=0
      XI=0
      XI2=0
C  REGRESSING GRAIN/STRAW ON FEEDRATE
      IF(LR.EQ.4)802,803
  802 DO 804 J=1,JM
      GI=GI+GS(J)
      GI2=GI2+GS(J)**2
      XI=XI+FEEDR(J)
      XI2=XI2+FEEDR(J)**2
  804 GIX=GIX+GS(J)*FEEDR(J)
      GIL=GI
      GO TO 806
  803 DO 805 J=1,JM
      GI =GI+GLN(J)
      GI2=GI2+GLN(J)**2
      XI=XI+FLN(J)
      XI2=XI2+FLN(J)**2
  805 GIX=GIX+GLN(J)*FLN(J)
      GIE=GI
  806 SX2=XI2-(XI**2)/EE
      SG2=GI2-(GI**2)/EE
      SXG=GIX-(XI*GI)/EE
```

```
      IF(LR.EQ.4)980,981
  980 SG2L=SG2
      GO TO 982
  981 SG2E=SG2
C  COMPUTING CORRELATION COEFFICIENT AND COEFFICIENT OF DETERMINATION
  982 RG2=(SXG**2)/(SX2*SG2)
      CG=RG2*100.0
      IF(SXG.LT.0)807,808
  807 RG=-1.0*SQRT(RG2)
      GO TO 809
  808 RG=SQRT(RG2)
      IF(LR.EQ.4)970,971
  970 RG2L=RG2
      RGL=RG
      GO TO 809
  971 RG2E=RG2
      RGE=RG
C  COMPUTING THE SLOPE,B
  809 BG=SXG/SX2
C  COMPUTING THE Y-INTERCEPT,A
      XB=XI/EE
      GB=GI/EE
      AG=GB-BG*XB
C  STORING THE RESIDUALS
      IF(LR.EQ.4)1835,1836
 1835 DO1837 J=1,JM
 1837 G11(J)=GS(J)-(AG+BG*FEEDR(J))
      GO TO 8888
 1836 DO1838 J=1,JM
 1838 G12(J)=GLN(J)-(AG+BG*FLN(J))
 8888 IF(LR.EQ.4)930,931
  930 AG10=AG
      BG10=BG
      GO TO 932
  931 AG20=AG
      BG20=BG
  932 IF(LR.EQ.4)812,813
  812 PRINT 814
  814 FORMAT(62X,10HLINEAR FIT/)
      GO TO 820
  813 PRINT 815
  815 FORMAT(60X,15HEXPONENTIAL FIT/)
  820 IF(LR.EQ.4)816,818
  816 PRINT 817,(AG,BG)
  817 FORMAT(*+*,48X,12HGRAIN/STRAW=,E10.3,1H+,E10.3,10H(FEEDRATE)/)
      GO TO 821
  818 PRINT 819,(AG,BG)
  819 FORMAT(*+*,45X,16HLN(GRAIN/STRAW)=,E10.3,1H+,E10.3,14H(LN(FEEDRATE
     1))/)
  821 PRINT 822,(RG)
  822 FORMAT(*+*,46X,35HCOEFFICIENT OF LINEAR CORRELATION =,F7.4,/)
      PRINT 823,(CG)
  823 FORMAT(*+*,46X,29HCOEFFICIENT OF DETERMINATION ,F5.2,7HPERCENT,/)
      IF(LR.EQ.4)801,826
C  REGRESSING LOSS RESIDUALS ON GRAIN/STRAW RESIDUALS
  826 PRINT 824
```

```
  824 FORMAT(*0*,42X,50HREGRESSING LOSS RESIDUALS ON GRAIN/STRAW RESIDUA
     1LS/)
  840 LR=LR+1
      IF(LR.EQ.6)830,831
  830 PRINT 814
      GO TO 832
  831 PRINT 815
  832 PRINT 833
  833 FORMAT(*+*,19X,9HRACK LOSS,35X,9HSHOE LOSS,35X,13HCYLINDER LOSS/)
      YR=0
      YR2=0
      YS=0
      YS2=0
      YC=0
      YC2=0
      XI=0
      XI2=0
      XIYR=0
      XIYS=0
      XIYC=0
      IF(LR.EQ.6)834,835
  834 DO 836 J=1,JM
      YR=YR+RER1(J)
      YR2=YR2+RER1(J)**2
      YS=YS+RES1(J)
      YS2=YS2+RES1(J)**2
      YC=YC+REC1(J)
      YC2=YC2+REC1(J)**2
      XIYR=XIYR+RER1(J)*G11(J)
      XIYS=XIYS+RES1(J)*G11(J)
      XIYC=XIYC+REC1(J)*G11(J)
      XI=XI+G11(J)
  836 XI2=XI2+G11(J)**2
      GO TO 838
  835 DO 837 J=1,JM
      YR=YR+RER2(J)
      YR2=YR2+RER2(J)**2
      YS=YS+RES2(J)
      YS2=YS2+RES2(J)**2
      YC=YC+REC2(J)
      YC2=YC2+REC2(J)**2
      XIYR=XIYR+RER2(J)*G12(J)
      XIYS=XIYS+RES2(J)*G12(J)
      XIYC=XIYC+REC2(J)*G12(J)
      XI=XI+G12(J)
  837 XI2=XI2+G12(J)**2
  838 SX2=XI2-(XI**2)/EE
      SXYR=XIYR-(XI*YR)/EE
      SXYS=XIYS-(XI*YS)/EE
      SXYC=XIYC-(XI*YC)/EE
C   COMPUTING THE SLOPE,B
      BR=SXYR/SX2
      BS=SXYS/SX2
      BC=SXYC/SX2
      IF(LR.EQ.6)940,941
  940 BRR10=BR
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```
      BRS10=BS
      BRC10=BC
      GO TO 942
  941 BRR20=BR
      BRS20=BS
      BRC20=BC
  942 IF(LR.EQ.6)841,842
  841 PRINT 843,(BR,BS,BC)
      GO TO 840
  843 FORMAT(*+*,1X,16H(LOSS RESIDUAL)=,E10.3,14H(G/S RESIDUAL),5X,
     116H(LOSS RESIDUAL)=,E10.3,14H(G/S RESIDUAL),5X,
     216H(LOSS RESIDUAL)=,E10.3,14H(G/S RESIDUAL)/)
  842 PRINT 844,(BR,BS,BC)
  844 FORMAT(*+*,1X,18HLN(LOSS RESIDUAL)=,E10.3,14H(LN(G/S RES)) ,
     13X,18HLN(LOSS RESIDUAL)=,E10.3,14H(LN(G/S RES)) ,
     23X,18HLN(LOSS RESIDUAL)=,E10.3,14H(LN(G/S RES)) /)
      PRINT 20,(SPEC(NK),NK=1,10)
      PRINT 845
  845 FORMAT(*0*,57X,20HMULTIPLE CORRELATION/)
      PRINT 846
  846 FORMAT(61X,12HLINEAR MODEL/)
      PRINT 833
C   DETERMINING EXPRESSION FOR MULTIPLE REGRESSION - LINEAR MODEL
      AAR=(-1.0*BRR10*AG10)+AR10
      BBR=(-1.0*BRR10*BG10)+BR10
      AAS=(-1.0*BRS10*AG10)+AS10
      BBS=(-1.0*BRS10*BG10)+BS10
      AAC=(-1.0*BRC10*AG10)+AC10
      BBC=(-1.0*BRC10*BG10)+BC10
      PRINT 850,(AAR,BBR,BRR10,AAS,BBS,BRS10,AAC,BBC,BRC10)
  850 FORMAT(*+*,3HPL=,E10.3,1H+,E10.3,4HFEED,1H+,E10.3,3HG/S,3X,
     13HPL=,E10.3,1H+,E10.3,4HFEED,1H+,E10.3,3HG/S,3X,
     23HPL=,E10.3,1H+,E10.3,4HFEED,1H+,E10.3,3HG/S/)
      PRINT 860
  860 FORMAT(41X,*SIMPLE CORRELATION COEFFICIENT - LOSS ON GRAIN/STRAW*/
     1)
      PRINT 833
C   DETERMINING EXPRESSION FOR MULTIPLE REGRESSION-MULTIPLICATIVE MODEL
      EAR=(-1.0*BRR20*AG20)+AR20
      EBR=(-1.0*BRR20*BG20)+BR20
      EAS=(-1.0*BRS20*AG20)+AS20
      EBS=(-1.0*BRS20*BG20)+BS20
      EAC=(-1.0*BRC20*AG20)+AC20
      EBC=(-1.0*BRC20*BG20)+BC20
C   DETERMINING SIMPLE CORRELATION COEFFICIENT - LOSS ON GRAIN/STRAW
      YGRL=0
      YGSL=0
      YGCL=0
      YGRE=0
      YGSE=0
      YGCE=0
      DO 861 J=1,JM
      YGRL=YGRL+PLR(J)*GS(J)
      YGSL=YGSL+PLS(J)*GS(J)
      YGCL=YGCL+PLC(J)*GS(J)
      YGRE=YGRE+RLN(J)*GLN(J)
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```
      YGSE=YGSE+SLN(J)*GLN(J)
  861 YGCE=YGCE+CLN(J)*GLN(J)
      SYGRL=YGRL-(GIL*YRL)/EE
      SYGSL=YGSL-(GIL*YSL)/EE
      SYGCL=YGCL-(GIL*YCL)/EE
      SYGRE=YGRE-(GIE*YRE)/EE
      SYGSE=YGSE-(GIE*YSE)/EE
      SYGCE=YGCE-(GIE*YCE)/EE
      RRRL2=(SYGRL**2)/(SYR2L*SG2L)
      CRL=RRRL2*100.0
      IF(SYGRL.LT.0)862,863
  862 RRRL=-1.0*SQRT(RRRL2)
      GO TO 864
  863 RRRL=SQRT(RRRL2)
  864 RRSL2=(SYGSL**2)/(SYS2L*SG2L)
      CSL=RRSL2*100.0
      IF(SYGSL.LT.0)865,866
  865 RRSL=-1.0*SQRT(RRSL2)
      GO TO 867
  866 RRSL=SQRT(RRSL2)
  867 IF(SYGCL.EQ.0)1380,1381
 1380 RRCL2=0.0
      CCL=0.0
      RRCL=0.0
      GO TO 870
 1381 RRCL2=(SYGCL**2)/(SYC2L*SG2L)
      CCL=RRCL2*100.0
      IF(SYGCL.LT.0)868,869
  868 RRCL=-1.0*SQRT(RRCL2)
      GO TO 870
  869 RRCL=SQRT(RRCL2)
  870 RRRE2=(SYGRE**2)/(SYR2E*SG2E)
      CRE=RRRE2*100.0
      IF(SYGRE.LT.0)871,872
  871 RRRE=-1.0*SQRT(RRRE2)
      GO TO 873
  872 RRRE=SQRT(RRRE2)
  873 RRSE2=(SYGSE**2)/(SYS2E*SG2E)
      CSE=RRSE2*100.0
      IF(SYGSE.LT.0)874,875
  874 RRSE=-1.0*SQRT(RRSE2)
      GO TO 876
  875 RRSE=SQRT(RRSE2)
  876 IF(SYGCE.EQ.0)1383,1384
 1383 RRCE2=0.0
      RRCE=0.0
      CCE=0.0
      GO TO 879
 1384 RRCE2=(SYGCE**2)/(SYC2E*SG2E)
      CCE=RRCE2*100.0
      IF(SYGCE.LT.0)877,878
  877 RRCE=-1.0*SQRT(RRCE2)
      GO TO 879
  878 RRCE=SQRT(RRCE2)
  879 PRINT 122,(RRRL,RRSL,RRCL)
      PRINT 499,(CRL,CSL,CCL)
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      PRINT 880
  880 FORMAT(50X,*COEFFICIENTS OF MULTIPLE CORRELATION*/)
      PRINT 833
C   DETERMINING RESIDUALS
      DO 883 J=1,JM
      PLRC(J)=AAR+BBR*FEEDR(J)+BRR10*GS(J)
      PLSC(J)=AAS+BBS*FEEDR(J)+BRS10*GS(J)
      PLCC(J)=AAC+BBC*FEEDR(J)+BRC10*GS(J)
      RER(J)=PLR(J)-PLRC(J)
      RES(J)=PLS(J)-PLSC(J)
  883 REC(J)=PLC(J)-PLCC(J)
C   DETERMINING MULTIPLE CORRELATION COEFFICIENTS
      YRLB=YRL/EE
      YSLB=YSL/EE
      YCLB=YCL/EE
      YREB=YRE/EE
      YSEB=YSE/EE
      YCEB=YCE/EE
      RHBL=0
      SHBL=0
      CHBL=0
      RYBL=0
      SYBL=0
      CYBL=0
      DO 1303 J=1,JM
      RHBL=RHBL+(PLRC(J)-YRLB)**2
      SHBL=SHBL+(PLSC(J)-YSLB)**2
      CHBL=CHBL+(PLCC(J)-YCLB)**2
      RYBL=RYBL+(PLR(J)-YRLB)**2
      SYBL=SYBL+(PLS(J)-YSLB)**2
 1303 CYBL=CYBL+(PLC(J)-YCLB)**2
      RMR2L=RHBL/RYBL
      CMRL=RMR2L*100.0
      RMRL=SQRT(RMR2L)
      RMS2L=SHBL/SYBL
      CMSL=RMS2L*100.0
      RMSL=SQRT(RMS2L)
      IF(CHBL.EQ.0)1304,1305
 1304 RMC2L=0.0
      RMCL=0.0
      CMCL=0.0
      GO TO 1306
 1305 RMC2L=CHBL/CYBL
      CMCL=RMC2L*100.0
      RMCL=SQRT(RMC2L)
 1306 RHBE=0
      SHBE=0
      CHBE=0
      RYBE=0
      SYBE=0
      CYBE=0
      DO 1309 J=1,JM
      RHBE=RHBE+((EAR+(EBR*FLN(J))+(BRR20*GLN(J)))-YREB)**2
      SHBE=SHBE+((EAS+(EBS*FLN(J))+(BRS20*GLN(J)))-YSEB)**2
      CHBE=CHBE+((EAC+(EBC*FLN(J))+(BRC20*GLN(J)))-YCEB)**2
      RYBE=RYBE+(RLN(J)-YREB)**2
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```
      SYBE=SYBE+(SLN(J)-YSEB)**2
 1309 CYBE=CYBE+(CLN(J)-YCEB)**2
      RMR2E=RHBE/RYBE
      CMRE=RMR2E*100.0
      RMRE=SQRT(RMR2E)
      RMS2E=SHBE/SYBE
      CMSE=RMS2E*100.0
      RMSE=SQRT(RMS2E)
      IF(CHBE.EQ.0)1310,1311
 1310 RMC2E=0.0
      RMCE=0.0
      CMCE=0.0
      GO TO 1312
 1311 RMC2E=CHBE/CYBE
      CMCE=RMC2E*100.0
      RMCE=SQRT(RMC2E)
 1312 PRINT 881,(RMRL,RMSL,RMCL)
  881 FORMAT(*+*,35HCOEFFICIENT MULTIPLE CORRELATION = ,F7.4,4X,
     135HCOEFFICIENT MULTIPLE CORRELATION = ,F7.4,4X,
     235HCOEFFICIENT MULTIPLE CORRELATION = ,F7.4/)
      PRINT 499,(CMRL,CMSL,CMCL)
C   ANOVA
C   DETERMINING ADDITIONAL REGRESSION DUE TO GRAIN/STRAW
C   PARTIAL CORRELATION COEFFICIENTS
      RYXXRL=((RRRL-(RRL*RGL))**2)/((1.0-RR2L)*(1.0-RG2L))
      RYXXSL=((RRSL-(RSL*RGL))**2)/((1.0-RS2L)*(1.0-RG2L))
      RYXXCL=((RRCL-(RCL*RGL))**2)/((1.0-RC2L)*(1.0-RG2L))
      RYXXRE=((RRRE-(RRE*RGE))**2)/((1.0-RR2E)*(1.0-RG2E))
      RYXXSE=((RRSE-(RSE*RGE))**2)/((1.0-RS2E)*(1.0-RG2E))
      RYXXCE=((RRCE-(RCE*RGE))**2)/((1.0-RC2E)*(1.0-RG2E))
      SSRL=RYXXRL*(1.0-RR2L)*SYR2L
      SSSL=RYXXSL*(1.0-RS2L)*SYS2L
      SSCL=RYXXCL*(1.0-RC2L)*SYC2L
      SSRE=RYXXRE*(1.0-RR2E)*SYR2E
      SSSE=RYXXSE*(1.0-RS2E)*SYS2E
      SSCE=RYXXCE*(1.0-RC2E)*SYC2E
      SMMRL=((1.0-RMR2L)*SYR2L)/(EE-3.0)
      SMMSL=((1.0-RMS2L)*SYS2L)/(EE-3.0)
      SMMCL=((1.0-RMC2L)*SYC2L)/(EE-3.0)
      SMMRE=((1.0-RMR2E)*SYR2E)/(EE-3.0)
      SMMSE=((1.0-RMS2E)*SYS2E)/(EE-3.0)
      SMMCE=((1.0-RMC2E)*SYC2E)/(EE-3.0)
      FRL=SSRL/SMMRL
      FSL=SSSL/SMMSL
      IF(SSCL.EQ.0)1340,1341
 1340 FCL=0.0
      GO TO 1342
 1341 FCL=SSCL/SMMCL
 1342 FRE=SSRE/SMMRE
      FSE=SSSE/SMMSE
      IF(SSCE.EQ.0)1344,1345
 1344 FCE=0.0
      GO TO 1346
 1345 FCE=SSCE/SMMCE
C   COMPUTING STANDARD ERROR OF THE ESTIMATE
 1346 SERL=SQRT(SMMRL)
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      SESL=SQRT(SMMSL)
      IF(SMMCL.EQ.0)1390,1391
 1390 SECL=0.0
      GO TO 1392
 1391 SECL=SQRT(SMMCL)
 1392 SERE=SQRT(SMMRE)
      SESE=SQRT(SMMSE)
      IF(SMMCE.EQ.0)1394,1395
 1394 SECE=0.0
      GO TO 1396
 1395 SECE=SQRT(SMMCE)
 1396 PRINT 312,(SERL,SESL,SECL)
      PRINT 882
  882 FORMAT(45X,*ADDITIONAL REGRESSION DUE TO GRAIN/STRAW*/)
      PRINT 123
      PRINT 124,(FRL,FTAB((JM-3),2),FRL,FTAB((JM-3),1),FSL,FTAB((JM-3),2
     1),FSL,FTAB((JM-3),1),FCL,FTAB((JM-3),2),FCL,FTAB((JM-3),1))
C   CHECK FOR SIGNIFICANCE
      IF(FRL.GT.FTAB((JM-3),2))2090,2091
 2090 MR2L=1
      GO TO 2092
 2091 MR2L=3
 2092 IF(FRL.GT.FTAB((JM-3),1))2093,2094
 2093 MR5L=1
      GO TO 2095
 2094 MR5L=3
 2095 IF(FSL.GT.FTAB((JM-3),2))2096,2097
 2096 MS2L=1
      GO TO 2098
 2097 MS2L=3
 2098 IF(FSL.GT.FTAB((JM-3),1))2099,2100
 2099 MS5L=1
      GO TO 2101
 2100 MS5L=3
 2101 IF(FCL.GT.FTAB((JM-3),2))2102,2103
 2102 MC2L=1
      GO TO 2104
 2103 MC2L=3
 2104 IF(FCL.GT.FTAB((JM-3),1))2105,2106
 2105 MC5L=1
      GO TO 2107
 2106 MC5L=3
 2107 IF(FRE.GT.FTAB((JM-3),2))3090,3091
 3090 MR2E=1
      GO TO 3092
 3091 MR2E=3
 3092 IF(FRE.GT.FTAB((JM-3),1))3093,3094
 3093 MR5E=1
      GO TO 3095
 3094 MR5E=3
 3095 IF(FSE.GT.FTAB((JM-3),2))3096,3097
 3096 MS2E=1
      GO TO 3098
 3097 MS2E=3
 3098 IF(FSE.GT.FTAB((JM-3),1))3099,3100
 3099 MS5E=1
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      GO TO 3101
 3100 MS5E=3
 3101 IF(FCE.GT.FTAB((JM-3),2))3102,3103
 3102 MC2E=1
      GO TO 3104
 3103 MC2E=3
 3104 IF(FCE.GT.FTAB((JM-3),1))3105,3106
 3105 MC5E=1
      GO TO 3107
 3106 MC5E=3
 3107 PRINT 125,(KSIG(MR2L),KSIG(MR2L+1),KSIG(MR5L),KSIG(MR5L+1),
     1KSIG(MS2L),KSIG(MS2L+1),KSIG(MS5L),KSIG(MS5L+1),KSIG(MC2L),
     2KSIG(MC2L+1),KSIG(MC5L),KSIG(MC5L+1))
      PRINT 71
      PRINT 121,(FEEDR(J),PLR(J),PLRC(J),RER(J),FEEDR(J),PLS(J),PLSC(J),
     1RES(J),FEEDR(J),PLC(J),PLCC(J),REC(J),J=1,JM)
      NOE=NOE+1
      GO TO 4000
  884 DO 885 IN=1,19
      PRINT 441,(GRR(IN,J,1),J=1,45),(GRR(IN,J,2),J=1,45),
     1 (GRR(IN,J,3),J=1,45)
  885 CONTINUE
      PRINT 20,(SPEC(NK),NK=1,10)
      PRINT 851
  851 FORMAT(57X,20HMULTIPLICATIVE MODEL/)
      PRINT 833
      PRINT 852,(EAR,EBR,BRR20,EAS,EBS,BRS20,EAC,EBC,BRC20)
  852 FORMAT(*+*,5HLNPL=,E10.3,1H+,E10.3,3HLNF,1H+,E10.3,4HLNGS,
     11X,5HLNPL=,E10.3,1H+,E10.3,3HLNF,1H+,E10.3,4HLNGS,
     21X,5HLNPL=,E10.3,1H+,E10.3,3HLNF,1H+,E10.3,4HLNGS/)
      AAR1=EXP(EAR)
      AAS1=EXP(EAS)
      AAC1=EXP(EAC)
      PRINT 853,(AAR1,EBR,BRR20,AAS1,EBS,BRS20,AAC1,EBC,BRC20)
  853 FORMAT(*+*,    3HPL=,E10.3,7H(FR)EXP,F6.3,8H(G/S)EXP,E10.3,
     11X,3HPL=,E10.3,7H(FR)EXP,F6.3,8H(G/S)EXP,E10.3,
     21X,3HPL=,E10.3,7H(FR)EXP,F6.3,8H(G/S)EXP,E10.3/)
      PRINT 860
      PRINT 833
      PRINT 122,(RRRE,RRSE,RRCE)
      PRINT 499,(CRE,CSE,CCE)
      PRINT 880
      PRINT 833
      PRINT 881,(RMRE,RMSE,RMCE)
      PRINT 499,(CMRE,CMSE,CMCE)
      PRINT 312,(SERE,SESE,SECE)
      PRINT 882
      PRINT 123
      PRINT 124,(FRE,FTAB((JM-3),2),FRE,FTAB((JM-3),1),FSE,FTAB((JM-3),2
     1),FSE,FTAB((JM-3),1),FCE,FTAB((JM-3),2),FCE,FTAB((JM-3),1))
      PRINT 125,(KSIG(MR2E),KSIG(MR2E+1),KSIG(MR5E),KSIG(MR5E+1),
     1KSIG(MS2E),KSIG(MS2E+1),KSIG(MS5E),KSIG(MS5E+1),KSIG(MC2E),
     2KSIG(MC2E+1),KSIG(MC5E),KSIG(MC5E+1))
C   DETERMINING RESIDUALS
      DO 854 J=1,JM
      PLRC(J)=AAR1*(FEEDR(J)**EBR)*(GS(J)**BRR20)
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      PLSC(J)=AAS1*(FEEDR(J)**EBS)*(GS(J)**BRS20)
      PLCC(J)=AAC1*(FEEDR(J)**EBC)*(GS(J)**BRC20)
      RER(J)=RLN(J)-(EAR+(EBR*FLN(J))+(BRR20*GLN(J)))
      RES(J)=SLN(J)-(EAS+(EBS*FLN(J))+(BRS20*GLN(J)))
  854 REC(J)=CLN(J)-(EAC+(EBC*FLN(J))+(BRC20*GLN(J)))
      PRINT 71
      PRINT 121,(FEEDR(J),PLR(J),PLRC(J),RER(J),FEEDR(J),PLS(J),PLSC(J),
     1RES(J),FEEDR(J),PLC(J),PLCC(J),REC(J),J=1,JM)
      NOE=NOE+1
      GO TO 4000
  856 DO 857 IN=1,19
      PRINT 441,(GRR(IN,J,1),J=1,45),(GRR(IN,J,2),J=1,45),
     1 (GRR(IN,J,3),J=1,45)
  857 CONTINUE
      RETURN
      END
```

SAMPLE DATA CARDS

```
 1 16.00 27.00    .36 24.00   6.00 19.00    .04    .10    .10
 2 16.00 34.50    .39 30.00   8.00 19.00    .06    .04    .09
 3 16.00 42.00    .29 34.00   8.00 36.00    .16    .04    .11
 4 16.00 40.50    .22 33.00  11.00 24.00    .73    .06    .10
 5 16.00 48.00    .24 35.00  10.00 24.00    .73    .06    .29
 6 16.00 51.00    .19 37.00  11.00 29.00    .56    .05    .28
 7 16.00 51.00    .18 35.00  12.00 31.00    .94    .13    .27
 8 16.00 57.00    .16 49.00  13.00 28.00   2.54    .13    .36
 9 16.00 60.00    .15 51.00  10.00 30.00   4.63    .11    .41
10 16.00 63.00    .13 56.00  10.00 32.00   6.13    .14    .78
 COCK. 431  T-1963  5    WHEAT  THATCHER WINDROW    3   ROSTHERN 30-9-63
 1 12.00 73.00    .48 31.00   4.00 27.00    .15    .24    .21
 2 12.00 62.00    .55 34.00   4.00 36.00    .17    .24    .18
 3 12.00 51.00    .47 30.00   2.00 34.00    .12    .15    .27
 4 12.00 66.00    .39 28.00   4.00 34.00    .07    .12    .25
 5 12.00 62.00    .32 28.00   2.00 19.00    .29    .19    .44
 6 12.00 44.00    .34 30.00   3.00 34.00    .20    .17    .31
 7 12.00 55.00    .25 31.00   2.00 26.00    .27    .17    .35
 8 12.00 42.00    .23 36.00   1.00 18.00   1.50    .24    .85
 9 12.00 67.00    .25 29.00   2.00 25.00    .27    .21    .56

 MF    82  AMS-10  2    WHEAT   SELKIRK WINDROW    3     ARCOLA  17-8-64
```

Instructions for Using the Program

Data preparation

Sample data cards, for loss tests on two machines, are shown on the previous page. The following rules should be observed in data preparation:

1. The program is based on a loss test consisting of a maximum of ten runs (ten individual loss collections). Data from loss tests consisting of ten runs, or less, can be processed; if more than ten runs are used, modifications to the program are necessary.

2. The format for punching the ten data cards is (I2, 9F6.2). Data is punched in the following order on each card: number of run, width of cut (feet), distance travelled (feet), length of run (minutes), weight of rack effluent - straw plus loss (pounds), weight of shoe effluent - chaff plus loss (pounds), grain collected in grain tank (pounds), rack loss (pounds), shoe loss (pounds), cylinder loss (pounds).

3. An eleventh data card, describing machine and crop specifications, is now inserted. The format for this card is (4A6, 6A8). Data is punched in the following order on this card: make of machine, model number, test number, test series number, crop type, crop variety, crop condition (windrowed or standing), straw condition, location, date.

4. If the test consisted of less than ten runs, blank cards must be inserted between the last data card and the specification card to make a total of eleven cards.

Interpretation of confidence intervals

The confidence intervals for the exponential model and simple exponential model (Figures 14 and 15) are based on the transformed data. These confidence intervals can be plotted only on linear coordinate paper. For example, in the exponential fit, if ln (percent loss) is plotted against ln (feedrate) on linear coordinate paper, then the confidence belt may be plotted directly, using the values given in the lower part of Figure 14. These are plotted as ln (percent loss) ± A. If the original data is to be plotted on "log-log paper", then the values for the confidence interval must be transformed as follows: For each feedrate, the confidence belt boundary will be located at antilog [ln (percent loss) + A] and antilog [ln (percent loss) - A]. Similarly, if the standard error of the estimate is used to express the confidence belt width, the value given in Figure 14 may be used directly if the transformed data is plotted on linear coordinate paper, but must be transformed, as above, if the original data is plotted on "log-log paper".

Graphs and residual plots

The scatter diagrams (Figure 13) are plotted to the nearest 10 lbs/min feedrate and to the nearest 1/2 percent loss. If the vertical or horizontal scale is exceeded, a plus (+) is used as the plotting symbol, rather than a star (*). The plus is placed at the upper limit of the axis which was exceeded.

The residuals (Figures 14 to 16) are plotted to the nearest 0.1 units. If the absolute value of the residuals is greater than 2, an "X" is used as the plotting symbol rather than a star (*).

The "X" is placed in either the (+2) or (-2) position.

Zero loss

If the value of percent loss is zero, for any particular run, the loss value is automatically changed to .01% before the data is fitted. This is necessary to avoid errors in fitting the exponential models, since $\ln(0) = -\infty$.

If cylinder loss data is not collected (as is sometimes done in combine loss measurements) and cylinder loss is entered as zero on all the data cards, computer error diagnostics will occur during the cylinder loss fitting process. These diagnostics refer only to the cylinder loss data; the rack and shoe loss data is still fitted correctly. The error diagnostics can be eliminated, in this case, by using fictitious cylinder loss data or by modifying the program to eliminate the cylinder loss fitting process.