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Machine and machine operator characteristics associated with corn harvest kernel damage

Hilbert John Hoof
Iowa State University

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Machine and machine operator characteristics associated with corn harvest kernel damage

by

Hilbert John Hoof

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INTRODUCTION

The practice of field shelled harvesting of corn has increased in popularity. The U.S. Department of Agriculture estimated field shelled harvesting of corn with combines has doubled, 24 to 48 percent of the crop, from 1964 to 1968 in the four major U.S. corn producing states of Iowa, Illinois, Indiana and Minnesota. Iowa figures for combine harvested shell corn show a similar trend, the four years 1967-1970 show 32, 35, 41 and 46 percent respectively of the corn combine harvested. Another 8 percent of the corn crop is picker shelled, making a total of 54 percent of Iowa corn harvested in shelled form in 1970 (20).

Combine harvesting of corn requires a minimum of labor. One man can operate the combine and unload shelled corn into waiting wagon boxes or trucks. The shelled corn can be unloaded at the storage, drying, or elevator sites by gravity flow. Shelled corn is easily conveyed mechanically to the desired drying and/or storage facility. Ease of mechanical handling, minimum labor for harvesting, hauling and conveying, plus corn reduced in bulk, shelled and ready for further processing or feeding are factors favoring the continued popularity of shelled corn harvesting.

Along with the increased efficiency of farm to market corn harvesting and handling methods, has come an increased concern about mechanical damage that occurs during these
operations. Country elevator operators, corn exporters, millers and warehousing operators are concerned with the effect of mechanical kernel damage on their operations.

Corn harvested and shelled with the present day combine threshing mechanism results in cracked and broken corn kernels. Saul and Steele (38) report kernel damage at 25 to 45 percent due to combine field shelling at harvest time. Investigations by Kline (25) suggest the corn damage is of a nature that does not affect the official grade received for freshly harvested corn as it enters the market. Broken corn affects the market grade when it is fine enough to pass through a 12/64 inch round-hole sieve. The necessary drying and further handling of such damaged corn does increase the amount of fine particles. Kline found that corn which averaged 0.6 percent broken corn and foreign material at harvest, averaged 13.8 percent broken corn after drying and processing through a simulated grain handling process. Mechanical damage at harvest apparently contributes to increased fines after handling. Handling tests of commercial corn also produced a similar magnitude of fines according to Winter (44).

The terminology, corn kernel damage, in this discussion refers to damage to corn kernels caused by machinery or impact rather than damage of a physical nature caused by insects, microflora, weather or heat. Kernel damage is here
defined as any breaks or cracks that fracture the kernel seed coat or separate the kernel into smaller parts. The kernel damage is herein categorized as "fines", "broken kernels", "cracked whole kernels" and, no visible damage, or "sound kernels".

Corn fines are corn particles that will pass through an agitated sieve having 12/64 inch round holes. Broken kernels are parts of kernels larger than fines but less than whole kernels. Cracked whole kernels have no parts missing, but have varying degrees of seed coat rupture. Sound kernels are kernels with no detectable breaks in the seed coat. The detectability of seed coat rupture varies with the detection process. The use of a fast-green dye stain increases detection of damage over damage detected among untreated corn kernels.

Corn fines together with foreign matter is one of the criterion used to establish the U.S. market grade of corn. The U.S. corn grading standards allow a maximum 2 percent corn fines and foreign matter in No. 1 yellow corn, 3 percent in No. 2, 5 percent in No. 4 and 7 percent in No. 5 yellow corn. Price discounts for fines and foreign matter are approximately one cent per bushel for each percent of fines and foreign matter up to 5 percent, and two cents per each percentage over 5 and up to 8 percent fines and foreign matter per bushel of corn. The U.S. market grade of corn
is not affected by kernel damage other than fines.

Fines from kernel damage produce certain problems in the corn industry. When corn is spouted into piles, bins or storage containers, the fines concentrate at the discharge point of the conical piles that develop. Unless a means of spreading the discharged corn is employed, a column of fines develops under the conical point of each pile of corn. These columns of fines create errors in grain sampling and grading as probes into the columns will show higher than average percentages of fines which will in turn lower the market grade.

The columns of fines also create bin drying and bin aeration problems. The mixture of particle sizes in the column of the pile reduces the void space, or inter-kernel space volume. The reduced void space results in higher resistance to air flow causing a problem of moisture removal, or heat removal, from the center volume of a corn pile. "Spoutlines" is a trade name for these columns. Slower drying, or heat build up, in the spoutlines increases the likelihood of corn spoilage, dry matter loss, heat damaged corn and market grade reduction. The possible production of aflatoxins by microorganisms growing in moist corn is another factor stressing the urgent need for uniform and rapid drying, or heat removal from shelled corn masses.

Certain definite costs can be attributed to kernel
damage. Field loss of fines, screening cost to remove excess fines, weight loss in grade and reduced value per bushel of screenings, grade reductions and price discounts to farmers due to fines, and reduced quality of milled corn products due to kernel damage, contribute to a lower net value of damaged corn.

The field losses of corn yield in the form of corn fines was investigated by Byg (4). The fines lost in the field accounted to 2.1 percent for 30 percent moisture corn, 1.3 percent for 25 percent moisture corn and 0.8 percent corn yield losses when corn was harvested a 20 percent moisture. For Iowa corn producers, assuming 40 percent of the crop is combine harvested at 25 percent moisture, this amounts to 4.8 million bushels of corn fines.

Approximately 13.5 percent of Iowa corn production moves into commercial market channels immediately after harvest (20). An additional 8 percent of the crop is stored commercially. These facts along with information (20) indicating 38.5 percent of Iowa corn is dried artificially, lead to an assumption that much combine harvested corn is mechanically dried. The increased corn fines resulting from the drying and handling of harvest damaged corn may necessitate screening to remove excess fines to maintain a No. 2 corn grade. Screening of corn costs approximately one cent per bushel (1). Additional value is lost due to an approximate
20¢ per bushel price discount on corn fines. Bailey (1) estimates fine removal and reduced value of corn fines result in a three cents per bushel value loss on all commercial corn. Corn fines in excess of the amount allowed for in No. 2 corn result in a reduction of market grade and the price received by the corn producer.

Broken kernels and cracked whole kernels are a concern to corn processors. The broken kernels reduce the particle size of corn grits that can be produced. Larger grits produce a more valuable corn product. The corn fines and larger kernel particles also influence the handling and processing costs for the wet corn processors. Any corn quality factors that reduce the product yield or add cost to the processing of corn are reflected in the market price bid by corn processors. The market price bids by corn processors in turn influence to some extent the market value of all corn.

Foreign markets are sensitive to United States corn quality. The price received for export corn, and the continuation and growth of our export markets, can be maintained and improved through improved corn quality. Reduced kernel damage is an important factor in improving the quality of export corn (6).

The market value of corn is influenced by the number of options open for its use. The U.S. corn trade has developed
discounts for various grade and value factors. Premiums are rarely paid for extra high corn quality. The individual corn producer, therefore, benefits mainly by avoiding price discounts and by producing a high quality product suited to a wide variety of uses. If a farmer produces corn suited only for livestock feed, the price is determined by the demand for livestock feed. When the corn can be sold for milling, export or feed, the corn has alternative uses which help assure maximum value for the corn producer's product.

Mechanical kernel damage is due to three basic factors; harvest shelling mechanisms, rapid cooling after hot air drying stress and market handling of shelled corn (25, 29, 12).

Mechanical damage of corn kernels cannot be reduced once it has occurred. Prevention of damage is required to maintain high corn quality.

This study was concerned with the investigation of agronomic, mechanical and human factors of the corn harvesting process and their relationship to kernel damage.

A knowledge of the causes of kernel damage coupled with the education of the corn producer is one potential means of reducing kernel damage. An educational program addressed to the problem of preventing kernel damage has the potential direct benefits of saving approximately 1.2¢ per bushel.
field losses and reducing price discounts from 1 to 11¢ per bushel. A corn producer can expect to gain an estimated 4¢ per bushel by applying practices that reduce kernel damage. Additional benefits of more efficient markets and strong domestic and foreign demands for corn accrue to corn with lower levels of damage.

The producer of 20,000 bushels of corn would gain $200.00 per year from each 1¢ per bushel added value to his crop. The economic impact of educational programs to reduce kernel damage can be estimated. The average Iowa farmer produces about 6,300 bushels of corn per year. At 4¢ a bushel, the average farmer would gain $252.00 per year by reducing harvest kernel damage. Iowa vocational agriculture programs enroll approximately 14,000 adult farmers in their educational programs. An average program with 61 adult farmers enrolled, and with 50 percent combining corn, thereby has the potential annual affect of $7,686.00 increased value of the corn produced by the enrollees. Present vocational agriculture programs enroll less than 10 percent of the farmers in their communities. An educational program resulting in reduced kernel damage by all farmers would total over $75,000.00 annually per community. Manpower and funds for serving all farmers are presently not adequate to the task. If one wishes to consider the effects per average county, using 100 counties and approximately
1,470 farmers per county, the possible benefits exceed $185,000. annually. One can begin to see the important effects an educational program combined with knowledge can have on the economy of rural Iowa.

The purpose of this study was to determine the relationship of selected agronomic, operator, and machine operation factors of shelled corn production to the percentage of kernel damage observed in freshly harvested corn. Specific objectives of the study were: (1) to identify those educationally useful characteristics of the machine operator that are significantly associated with corn kernel damage incurred during the harvest operation, (2) to identify those educationally useful factors of machine operation that are significantly related to harvest incurred damage to shell corn, and (3) to identify some selectable agronomic practices of corn production significantly related to harvesting damage to shell corn.

This study was aided through the cooperation, efforts and/or support of the National Corn Growers Association, the Iowa Development Commission, the Iowa Agricultural Marketing Board, the Farm Grain Dealers Association of Iowa, U.S.D.A. Marketing Services, Iowa State Agricultural Engineering Department, and Gerald Kline of the Iowa State Agricultural Research Service.
REVIEW OF LITERATURE

The teaching of accumulated knowledge, and the acquisition of new knowledge and its application are means by which man progresses in individual knowledge, understandings of phenomena and skill development. The concerns of this study were specifically related to agricultural education and the harvesting of high quality shelled corn.

A review of studies related to the educational aspects of agricultural mechanics indicates a need for agricultural mechanics instruction for farmers and corn harvest machine operators.

Farm Practices

Farm machinery care, maintenance and adjustment is one area of agricultural mechanics for which farmers rely largely on their own knowledge and skill to complete the variety of tasks performed on a farm. A study by Murray (31) of 15 farm power, 15 farm machinery and 15 electrical practices used by Southern Minnesota farmers indicated 85 percent of the farm machinery practices were carried on by the farmer himself. More use was made of commercially available, skilled personnel in the areas of farm power and electrification. Farmers completed 64 and 50 percent respectively, of their own farm power and electrical practices. Montana farmers appear
to be similarly involved in their own machinery care.

Pruett (36) randomly selected 100 Montana farmers and found that 75 percent had farm shops and completed 70 percent of their own needs for repair, maintenance, and farm construction.

The recognition that machines are an extension of the farmer's physical power, and that machine operations are conducted in a race with crop operation timeliness and adverse weather, allows one to understand the importance of mechanical skills and understandings to the farmer.

Need for Training

The point has been made that farmers do much of their own mechanical work, yet many individual farmers express a need and desire to be capable of doing more.

Rodgers (37) found Ohio young farmers faced two major personal difficulties, one of which was a lack of mechanical skills. A lack of training in mechanical skills was also expressed as a concern by adult farmers in Maryland and Colorado. More than two-thirds of the Maryland (40) farmers surveyed, gave "a lack of training" as the reason for not performing more mechanical tasks. Mattoon (28) received a similar response from farmers in his area. A need for training limited the tasks performed by Colorado farmers. A lack of knowledge or skill that limits a man is more severe
than a desire to possess more knowledge or skill.

Felt needs and desires for the possession of more mechanical skills also existed among farmers as found by Field (13), Jensen (21) and Wagoner (43). Jensen surveyed 2,464 Wisconsin farmers and found over 50 percent responded by expressing a need for training in 95 of 143 mechanical skills suggested to them. Field, in Indiana, and Wagoner, in Iowa, surveyed youth opinion concerning skill needs. The farm youth had not necessarily decided if they would pursue farm or non-farm careers. Those youth surveyed by Field indicated that within the areas in agricultural education, agricultural mechanics was the area of greatest need.

Wagoner's survey indicated young men on farms, 17 to 22 years of age, by a large majority, desired more mechanical training. The desire for more training varied according to the kind of previous training. On-the-job trained men totaled 55 respondents, 37 wanted more training. Seventy-three of the 94 who had experienced formal mechanical training desired more education. Those with no training in mechanics were less desirous of more help, as only 33 of the 72 so grouped desired more training. A group of 26 young men were employed in farm implement businesses; 50 percent of those employed for one year desired more knowledge. Ten of the 11 employed more than one year, wanted more training. Wagoner also included a self-rating question in his survey. An interesting result of
the self rating is that mechanical understandings and abilities possessed were found to be correlated with self ratings at highly significant levels (.61 and .62).

Davis (7) studied the need for mechanical education in his Tennessee school district. A survey showed approximately 15 percent of the machinery on farms were not properly adjusted. Farmers with sons in the all day vo-ag classes had their machinery in slightly better adjustment than the farmers without sons who were vo-ag students. Davis concluded approximately 40 percent of the farmers needed instruction to properly adjust those machines found to be out of adjustment.

A survey to determine the opinion of former vocational agriculture students concerning the course content in mechanics was conducted by Kindschy (24). The survey questionnaire was composed of mechanical abilities to be rated as "important", "of little importance" or "should not be included" by the respondent. The 246 former students who responded, represented 5 economic areas of Iowa. The farm implement repair section contained a list of 23 abilities. A majority of the respondents rated 15 of the 23 as "important".

The highest rating was given to the item "maintain and adjust implements common to Iowa farms". Items concerning adjustment and repair of specific machines were strongly
endorsed as "important" by 81 to 91 percent of the young men.

Competency Studies

A study in Kansas by Patry (34) of the farm machinery competencies needed by farmers, involved obtaining the opinions of 20 selected farmers and seven selected farm machinery dealers. The subjects were asked to rate, on a 0 to 4 scale, the machine competencies which should be taught in vocational agriculture. Those machines that received the highest ratings (above 2.5, 2 = important and 3 = very important) by the farmer and machinery dealer groups were (1) tractors, (2) combine harvesters, (3) balers, (4) grain drills, (5) plows and (6) pesticide and insecticide applicators.

Two Iowa studies, one by Kordick (26) and one by Johnson (22) involved the compilation of lists of approximately 50 competencies each considered important by panels of consultants. Kordick was concerned with the competency needs of farmers in the management of farm machinery. The study involved responses from farmers in a nine-county area in southwest Iowa. Of the several competencies rated above 3.0 (much competency needed) by the respondents, two related to this study were: (1) to determine skill as an operator of a machine, and (2) to determine machine capacity per hour or day.
The study by Johnson was concerned with corn production abilities needed by farmers. Two groups of farmers, 110 classified as master corn growers and 82 randomly selected farmers, rated a list of competencies needed in corn production. The proper use of machinery to minimize harvest damage and losses, was rated highest by the master corn growers. The same competency also received a high rating by the randomly selected farmers.

Needs expressed may also be considered desires not met. Educational programs will vary some from one part of the country to another.

Agricultural mechanics instruction includes a broad area of knowledge. The Instruction in Agricultural Mechanization Committee of the American Society of Agricultural Engineers (11) lists five areas of instruction in agricultural mechanics, they are: (1) farm power and machinery, (2) structures and environment, (3) soil and water management, (4) electric power and processing, and (5) agricultural construction and maintenance.

The educator must be learned and experienced to provide skills training.

Dettmann (8) made a study of the agricultural mechanics competencies needed by 156 vocational agriculture instructors in Iowa. A wide difference was revealed between competence possessed and competence needed in the area of operating
principles, adjustment, and maintenance of farm tractors and machinery.

West Virginia vocational agriculture teachers indicated that the farm machinery instruction area was not extensively taught, yet they rated many farm machinery skills compiled by O Dell (33) as being very important to farmers.

Hutson (18) surveyed instructors in 90 vo-ag departments in Arkansas. The instructors rated farm power and farm machinery as the two most difficult instructional phases of farm mechanics. A need for more teacher preparation in farm power and machinery was implied.

A study of mechanical skills, abilities and understandings needed and possessed by teachers of agriculture in Pennsylvania involved 133 vo-ag instructors. Hoerner (17) grouped farm mechanics skills into seven areas for the study, one was power and machinery. The selection, operation, adjustment, and maintenance of combines and corn pickers was rated as much needed. The difference between competence needed and possessed was statistically highly significant.

This study indicated a significant advantage in competence possessed by teachers with 15 or more credits compared to those with zero to 14 credits in agricultural mechanics.

The recognition of deficiencies can lead to alternatives other than increased teacher preparation, one of which is the use of more resource persons in the classroom. Adequate
knowledge and opportunity for skill development apparently does not exist on the farms. Expertise and knowledge must be brought to the agricultural producer.

Education

The impact of education on the practices applied by former students of vocational agriculture was attested to by two studies widely separated by time. Ball (2) in 1956, and Diggins (9) in 1940, found significant and convincing evidence of improved operational practices applied by former students following instruction received in vocational agriculture classes.

A more complex and carefully controlled study of the effectiveness of education and skills training on worker efficiency was made by Fuller (14). Fuller selected five variable categories: (1) general education, (2) trade training, (3) work experience, (4) environmental characteristics, and (5) family dependents to predict worker efficiency. The model for the study was (14, p. 11):

\[ Y_t = a + b_1X_1 + b_2X_2 \ldots + b_nX_n + U \]

where:

- \( Y_t \) = worker efficiency at a given time
- \( X_1-X_n \) = independent variables
- \( b_1-b_n \) = coefficients expressing the strength of relationships between \( Y_t \) and \( X_1-X_n \)
a = the intercept
U = error term

Following is a summary of his findings:

(1) years of general education beyond eight years, had a significantly positive, but minor effect on worker efficiency,

(2) job training was most effective when provided in the firm under future working conditions,

(3) the effect of work experience on efficiency was unclear, tended to be positive in beginning years, and tended to negative in later years.

Maton (27) questioned the effectiveness of education in preparing men for jobs. His study compared workers with different backgrounds in an attempt to analyze the effects of various educational and experience backgrounds on job success. Maton found education effective as a substitute for on-job experience, but questioned the cost efficiency, when alternative uses of time are considered.

This study is concerned with improving the operation and performance of man and machine in the corn harvesting operation. An assumption that increased knowledge and training on the part of corn combine operators can result in less harvest damage to corn is proposed. The mechanical aspects of kernel damage have been studied by several investigators.
Corn Shelling Phenomena

The mechanics of ear corn shelling were studied by Johnson and associates (23). This laboratory study involved the application of various known impact loads to corn ears of varying moisture content. The ears were impact loaded in two different orientations, axially with the ear length in line with the applied force and tangentially with the ear length perpendicular to the line of force. The conclusions reported from the analysis of results and observations were as follow: (1) kernel removal is a result of kernel deflection on the cob caused by an external force, (2) shelling occurs due to stress transmission between kernels rather than due to cob deflection, (3) transverse loading of the ear produces longitudinal quartering and axial loading results in transverse sectioning of the cob, (4) shelling is a failure of the pedicel attachment caused by bending and tension transferred to the kernel by side contacting forces, (5) tensile stresses of the kernel tip are low, (6) shelling energy required per pound of corn shelled decreases with increased impact momentum, (7) shelling energy requirements increase with increased moisture content, (8) shelling energy requirements did not vary significantly due to mode of ear loading (axial vs. transverse), and (9) kernel cracking was higher for axial ear loading and at higher ear moisture contents.
Factors Influencing Shelling Damage

An effort to predict the threshing damage from a knowledge of the physical and morphological characteristics of corn was made by Waelti (42). A prediction equation considering sixteen kernel and cob characteristics was designed. Laboratory measures were made of each characteristic. Portions of the various corn samples were laboratory and field combined. A conventional rasp-bar concave-cylinder threshing unit was used. The kernel damage was measured as the dependent variable.

Analysis of the data resulted in the refinement of the prediction equation to include only five of the original 16 predictor variables. The final prediction equation accounted for 51.6 percent of the damage variation and was statistically significant at the 1 percent level. The force required to detach kernels, kernel strength, initial kernel thickness (largely a function of moisture), final kernel thickness, and cob strength were the five ear and cob characteristics remaining in the revised prediction equation.

Waelti observed a significant variation in damage due to corn variety. Planting date did not appear to influence kernel damage.

The moisture content of corn at harvest-shelling time appears to be an important factor in the amount of mechanical
damage inflicted to the kernel. In general, kernel damage is reported as being lowest at 20 percent kernel moisture.

Barkstrom (3) worked with dry corn and found fines increased with moisture content below 20 percent. Waelti (42) and Morrison (30) noted increasing kernel damage with increasing moisture content above 20 percent. Hall (16) worked with corn that varied from 10 to 37 percent moisture and found the lowest damage levels were with corn containing 20 and 24 percent moisture.

Variations in cylinder bar and concave shapes, and materials, have been tested in an effort to reduce kernel damage and yet retain shelling efficiency. Standard rasp bars, wide spaced rasp bars, rubber coated bars, angles and channel bars were tested on the standard type combine cylinder. No variations were found by Cooper (5) nor by Pickard (35) which significantly reduced damage below levels produced by the standard rasp bar. Pickard also varied the concave surfaces, but found the steel rasp cylinder and channel concave to produce as low a breakage level as other combinations tested.

The use of filler plates between the cylinder bars and a cover plate on the lead edge of the concave gave slightly reduced kernel damage effects as tested by Morrison (30).

Variation in the operating speed of the combine cylinder is another factor influencing combine threshing performance
and levels of kernel damage. Hall (16) noted significantly lowered kernel damage levels when the cylinder speed was lowered from 600 to 500 to 400 revolutions per minute. A similar relationship of kernel damage and cylinder speed was noted by both Goss et al. (15) and Morrison (30).

In addition to kernel damage, Morrison measured corn losses due to incomplete ear shelling. Corn losses increased at lower, less damaging cylinder speeds. Pickard (35) also noted the corn loss effect of lower cylinder speeds. Corn losses were reduced to minimum levels at slower, less damaging cylinder speeds, when Morrison added filler plates between the cylinder rasp bars.

Summary

The studies reviewed indicate that, over time and in various parts of the country, both farm youth and established farmers consider farm machinery skills and knowledge important to success in their occupation. Studies involving teachers of vocational agriculture portrayed a similar need for comprehensive knowledge and skill in the farm machinery phases of agricultural mechanics. Teachers tend to be more competent instructors when adequately prepared. Education combined with practical experience are effective means of developing competence in farm machine maintenance and operation.
The popular and efficient present day practice of shelled-corn harvesting provides a complex variety of economically significant problems. Further information about the phenomena and interaction of factors influencing the shelled-corn harvesting process is needed. Such information can be of value to the educator, the producer, the agricultural engineer and the seed corn producer.
METHOD OF PROCEDURE

The investigation of factors related to the occurrence of kernel damage during the harvesting of shelled corn required the collection of information and the obtaining of corn samples during the harvest season.

Information was needed about the harvesting machine operator to determine relationships that may exist between measurable variations in human characteristics and the results of machine operations.

Evidence has been presented to indicate the need for information on the specific adjustments and operating speed of the harvesting machine.

The possibility of agronomic practices affecting harvest kernel damage also existed. Information concerning the agronomic practices under which the corn was produced and harvested was required for analysis.

The desire to study the relationship of corn production and harvesting factors, and the nature and extent of kernel damage in new corn as it leaves the farm required the gathering of information and corn samples as the harvesting occurred.

The confounding influences of weather, marketing decisions, machine breakdowns and substitution, and harvesting alternatives created serious problems relative to the identification of men, machines and agronomic factors
necessary in any specific sampling scheme. A decision was reached to try to obtain samples representative of the normal movement of freshly shelled corn as it leaves the farm and enters the commercial markets in central Iowa.

Very valuable assistance was found to be available for this investigation from Gerald Kline (25) and staff. A project by Kline was underway which also required the obtaining of freshly shelled corn samples. Cooperation was established with Kline whereby the efforts of this study could supplement his efforts and the information gathering instrument could be modified to serve two purposes. The approval of the sponsors, recognized in the introduction for Kline's project was obtained.

The independent variables selected for this study were those readily obtainable at harvest time through the cooperation of the harvest machine operator and the corn producer. The dependent variables selected were those ascertainable through existing governmental agencies.

Independent Variables

The agronomic factors selected were: (1) harvest date, (2) variety of seed corn, (3) estimated yield per acre, (4) corn row spacing, (5) corn standability, lack of lodging, (6) moisture content of corn at harvest, and (7) corn test weight at harvest time.
The machine factors selected for study were: (1) make and model of combine or picker-sheller, (2) size of header unit, (3) cylinder revolutions per minute, (4) cylinder rpm adjusted to equate peripheral speed of travel for all cylinder diameters, (5) front cylinder-concave clearance in inches, (6) rear cylinder-concave clearance in inches, (7) ground speed of machine in miles per hour, (8) estimated harvest rate in bushels per hour, and (9) harvest rate in bushels per cylinder inch per ten hours.

The operator, or human factors, selected were: (1) age, (2) highest grade of formal education, (3) years of high school vo-ag (vocational agriculture) completed, (4) participation in adult or young farmer (post high school) vo-ag classes, (5) farming status; owner, custom, hired, (6) years of combine operation experience, (7) annual acreage of combine operation experience, (8) main source of knowledge of combine operation (experience, trained by experienced operator, study of operating manual, educational classes on machine operation, machinery dealers or service man, magazine articles), (9) self-rated mechanical interest and ability, (10) machine adjustment frequency per day.
Dependent Variables

The corn quality and damage analyses were obtained from three sources. The quality information based on official market information of freshly harvested corn included: (1) moisture content, (2) test weight, (3) damaged kernels and heat damage (other than mechanical damage), (4) broken corn and foreign matter passing 12/64 inch screen, and (5) market grade.

The corn damage indices based on tests by the Iowa State Seed Laboratory were: (1) percent foreign material and fine corn passing through a 12/64 inch round-hole screen, (2) percent broken corn of less than whole kernel size over a 12/64 inch screen, (3) percent whole kernels with damaged pericarp, (4) percent sound kernels, and (5) percent germination of the corn.

An indication of the effect of harvest damage on subsequent breakage during commercial handling was obtained by a simulated handling test of each sample. The unit of measure for breakage susceptibility was the percentage of material passing through a 12/64ths inch round-hole sieve after the simulated handling treatment.
Questionnaire

The questions needed to gather the desired information were arranged on a one page questionnaire. This questionnaire, along with a brief explanation, was given to farmers, or haulers of fresh corn, at the sampling site. The subject was asked to fill in the form, or take it home and return the form, when completed, to the sampling site. The questionnaire is shown in the Appendix.

Corn Samples

Corn sampling sites were selected within a serviceable radius of Ames, Iowa. The sampling sites chosen were commercial grain elevators which had the grain handling capacity to receive corn during the full harvest season. The cooperation and interest of the management was established before sampling was initiated.

Corn sampling began near the start of the 1970 corn harvesting season and continued at twice weekly intervals during the most of the harvest season. The corn samples were taken as trucks or wagons unloaded at the elevator. A sample consisted of 3 quarts of corn obtained intermittently during the dumping of the load or taken with a load sampling probe. The original sample was split into two parts. One part was sealed in a plastic bag and refrigerated for market
grading. The other part of the sample was air dried and split for the Ames Seed Laboratory tests and the simulated handling breakage test.

Kernel Damage Determination

The fresh, refrigerated corn samples were taken to the USDA Consumer and Marketing Service Grain Division Laboratory in Des Moines, Iowa. The sample was graded according to current market standards for corn.

One portion of the air dried part of each sample was analyzed at the Iowa State Seed Laboratory, Ames, Iowa. Foreign matter and fines (less than 12/64 inch size); broken, chipped and crushed corn over 12/64 inch size; whole kernels with damaged pericarp; sound kernel; and germination percentages were determined.

The second air dried portion of the samples was taken to the USDA Agricultural Research Service, Market Quality Research Division Laboratory in Manhattan, Kansas. The samples were treated with a grain handling simulator, and the percentage of corn fines passing through a round 12/64 inch screen was determined.
Statistical Treatment

Means, standard deviations and frequency counts were computed from the raw data. A Pearson product-moment correlation matrix, employing pair-wise deletion on missing data, was computed on the data to establish the nature, degree and significance level of variable correlations.

The response range for each independent variable was divided into response intervals. The intervals were then treated as classes.

Any variations in the percentage of kernel damage observed among corn samples needed to be explained. The question was whether the differences in damage observed occurred at random, or whether those damage variations were associated with variations in the factor measured as an independent variable. A test of the F-value produced by single classification analysis of variance was made to examine the nature of kernel damage variance. The null hypothesis tested by single classification analysis of variance, stated generally was:

$H_0$: There is no statistically significant difference among the dependent variable means for the classes, within the response range of the independent variable.
The possibility existed that even if no individual independent variable was associated with the degree of kernel damage, a combination of two or more might exhibit an association with the amount of kernel damage.

Step-wise regression was chosen as a means by which the effect of combined independent variables could be established and the variance associated with the resulting regression equation could be tested for statistical significance.

In order to reduce the likelihood of chance associations, due to the large number of independent variables, appearing actual, a reduction in the number of independent variables was in order. Factor analysis was applied to the data to reduce the number of independent variables. Factor analysis does not offer a unique solution for data reduction. A factoring technique which would reduce the number of independent variables and maximize the variance between the resultant factors was chosen. Rotated orthogonal factor analysis was applied to the independent variables (32).

The reduced number of factors resulting from factor analysis were treated as a new set of independent variables. Stepwise regression of the factorized independent variables on each measure of kernel damage was computed. The resulting regression equations were tested by analysis of variance F test.
The null hypothesis tested by regression analysis of variance was:

Ho: The slope of the regression line is zero.

The null hypotheses were rejected when the F-value, with the appropriate degrees of freedom (39) could be expected to occur five or less percent of the time due to chance. Throughout the findings chapter a single asterisk denotes F-values significant beyond the five percent level and two asterisks denote significance beyond the one percent level.

Statistical Models

The model for single classification analysis of variance was:

\[ Y_{ij} = \mu + \alpha_i + e_{ij} \]

where:

\[ Y_{ij} = \text{the measurement of the damage descriptive factor of the jth observation in the ith treatment level.} \]

\[ \mu = \text{the mean damage over all samples} \]

\[ \alpha_i = \text{effect of the ith treatment level} \]

\[ i = 1...a \text{ (number of treatment levels)} \]

\[ j = 1...n \text{ (number of observations)} \]

\[ e_{ij} = \text{effect due to error } \sim N(0,\sigma) \]

The model for stepwise regression was:
\[ Y_{ij} = c + b_1X_1 + b_2X_2 + \ldots, b_iX_i + e_{ij} \]

where

- \( Y_{ij} \) = the \( j \)th observation of the \( i \)th variable
- \( c \) = the height of the regression line at its origin (\( Y \) axis)
- \( b_1 \ldots b_i \) = the partial regression coefficient of \( Y \) on \( X_1, \ldots, X_i \)
- \( X_1, \ldots, X_i \) = the independent or predictor variables
- \( e_{ij} \) = the effect due to error \( \mathcal{N}(0, \sigma) \)
- \( i = 1 \ldots a \) (number of predictor variables)
- \( j = 1 \ldots n \) (number of observations per predictor variable)

The principal-component model for factor analysis (32) was:

\[ Z_j = a_{j1}F_1 + a_{j2}F_2, + \ldots, + a_{jm}F_m + d_jU_j \]

where

- \( Z_j \) = the variable
- \( F_i \) = each factor common to some degree for each variable
- \( U_j \) = a unique factor for each variable
- \( a_{ji} \) = regression weights
- \( d_j \) = regression weight
- \( j = 1 \ldots n \) (number of variables)
- \( i = 1 \ldots n \) (number of common factors)
FINDINGS

The findings presented are based on the results of the compilation and statistical treatment of information concerning characteristics of machines, of machine operators and of agronomic conditions obtained with the collection of 209 freshly harvested shelled corn samples, and an analysis of the physical condition of those samples.

Harvesting Factors and Kernel Damage Measures

Means and standard deviations for 34 of the 40 itemized variables studied are presented in Tables 1 through 4. The six items regarding the machine operator's main source of operating knowledge are found in Table 5. The data indicating the main source of knowledge was treated as response - no response information which did not yield means nor standard deviations. In observing data in Tables 1 through 4, it should be recognized that a majority of approximately 68 percent of the values will be within ± 1 standard deviation from the mean for normally distributed data.

The agronomic variables in Table 1 are descriptive of corn crop conditions during the harvest period. The mean crop standability of 1.57 indicates lodging was not a serious problem. The moisture content was relatively low, average 21 percent, and did not vary widely over the season and
Table 1. Means and standard deviations for the agronomic independent variables

<table>
<thead>
<tr>
<th>Agronomic Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn test weight, lbs.</td>
<td>54.48</td>
<td>1.64</td>
</tr>
<tr>
<td>Crop standability, coded(^a)</td>
<td>1.57</td>
<td>0.70</td>
</tr>
<tr>
<td>Damaged kernels and heat, %</td>
<td>1.78</td>
<td>1.22</td>
</tr>
<tr>
<td>Date of harvest, coded(^b)</td>
<td>172.2</td>
<td>67.08</td>
</tr>
<tr>
<td>Moisture of corn at harvest, %</td>
<td>21.18</td>
<td>1.91</td>
</tr>
<tr>
<td>Row spacing of crop, inches</td>
<td>36.43</td>
<td>3.35</td>
</tr>
<tr>
<td>Variety of corn, coded(^c)</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>Yield per acre, bu.</td>
<td>110.13</td>
<td>17.40</td>
</tr>
</tbody>
</table>

\(^a\)Corn standability - 1 = mostly upright, 2 = some lodging, 3 = lodged over 25%.

\(^b\)Date code - October = 100, November = 200, December = 300, date of month = 1-31, Oct. 1 = 101.

\(^c\)Corn varieties were numbered and grouped by brand to facilitate sorting, varieties and frequencies are found in Table 10.

samples as indicated by a 1.91 percent standard deviation for moisture content. The majority of samples were between 19 and 23 percent moisture. Yields were above the state average of 85.6 at 110 bushels per acre indicated for the samples. The mean row width of 36.43 inches with a 3.34 inch standard deviation suggested 36 inch rows were common with some 30
inch and some 38 and 40 inch rows also used.

The operator variables and the mean results of each item are displayed in Table 2. The mean age of operators was approximately 43 years with the majority of operators between 21 and 55 years of age. Combining experience varied widely in both years and acres. The mean experience was substantial at 10 years and just over 500 acres per year of combining experience. Generally education was near the 12th grade level. Some older eighth grade graduates plus men with some high school, but less than four years, more than offset the number of operators with over 12 years of education as the mean of 11.77 years of education illustrated. Years of high school vo-ag, with a mean of 1.57 compared with a mean of 11.77 years of education, indicated approximately one-third of the potential vocational education had been received by the operators. Post-high school vo-ag classes, or adult and young farmer classes, were attended by over 10 percent of the operators as indicated by the Table 2 post-high school vo-ag mean of 1.23. A mean of 1.20 would have indicated a 10 percent membership in adult farmer classes.

The machine operators tended to be owner-operators as indicated by the 1.31 farming status mean. Most operators adjusted their machines more than twice a day and self ratings indicated medium-strong mechanical interests and abilities.
Table 2. Means and standard deviations for the human or operator independent variables

<table>
<thead>
<tr>
<th>Operator Variables</th>
<th>Mean</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, coded&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.34</td>
<td>1.17</td>
</tr>
<tr>
<td>Combining experience, years</td>
<td>9.97</td>
<td>8.66</td>
</tr>
<tr>
<td>Combining experience, acres per year</td>
<td>505.29</td>
<td>346.94</td>
</tr>
<tr>
<td>Education, general, years</td>
<td>11.77</td>
<td>1.80</td>
</tr>
<tr>
<td>Years of high school vo-ag instruction</td>
<td>1.57</td>
<td>1.65</td>
</tr>
<tr>
<td>Post high school vo-ag class membership, coded&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.23</td>
<td>0.60</td>
</tr>
<tr>
<td>Farming status, coded&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1.31</td>
<td>0.69</td>
</tr>
<tr>
<td>Frequency of machine adjustment per day, coded&lt;sup&gt;d&lt;/sup&gt;</td>
<td>2.64</td>
<td>1.18</td>
</tr>
<tr>
<td>Mechanical ability, coded&lt;sup&gt;e&lt;/sup&gt;</td>
<td>2.40</td>
<td>0.50</td>
</tr>
</tbody>
</table>

<sup>a</sup>Operator age was coded - 1 = < 25 yrs, 2 = 25-34 yrs, ..., 5 = 55-64, 6 = 65 and over.

<sup>b</sup>Post-high school vo-ag class membership coded - 1 = zero membership, 2 = young farmer class member, 3 = adult farmer class member.

<sup>c</sup>Farming status - 1 = own machine, 2 = hired man, 3 = customs operator.

<sup>d</sup>Frequency of adjustment - 1 to 3 = times per day, 4 = several times a day.

<sup>e</sup>Mechanical interest and ability rating - 1 = low, 2 = medium, 3 = high.
Information on the operation of the harvesting machines is summarized in Table 3. The mean cylinder speed of 544 and the front and rear concave clearances of 1 inch front,

Table 3. Means and standard deviations for the machine operation independent variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combine make, coded</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>Cylinder, rpm</td>
<td>543.74</td>
<td>101.36</td>
</tr>
<tr>
<td>Cylinder, rpm, adjusted</td>
<td>522.58</td>
<td>97.22</td>
</tr>
<tr>
<td>Front concave-cylinder clearances, inches</td>
<td>1.01</td>
<td>0.47</td>
</tr>
<tr>
<td>Rear concave-cylinder clearance, inches</td>
<td>0.81</td>
<td>0.51</td>
</tr>
<tr>
<td>Ground speed, mph</td>
<td>3.17</td>
<td>0.75</td>
</tr>
<tr>
<td>Harvest rate, bu./hr.</td>
<td>290.89</td>
<td>128.73</td>
</tr>
<tr>
<td>Harvest rate, bu./cyl. in/10 hrs.</td>
<td>81.73</td>
<td>50.33</td>
</tr>
<tr>
<td>Header size, rows</td>
<td>3.16</td>
<td>1.05</td>
</tr>
</tbody>
</table>

^aCombine makes were coded for numerical identification, makes and frequencies are found in Table 28.

^bCylinder speed was adjusted to equate peripheral speed variations due to diameter variations.

.8 inch rear, were in agreement with generally recommended settings for corn combining. The combination of mean ground speed (3.17 mph), mean header size (3.16 rows), mean row
spacing (36.43 inches) and mean corn yield (110 bu. per acre), compared to an indicated harvest rate of 291 bushel per hour indicated a combine field efficiency of approximately 72 percent which was reasonable.

The kernel damage measures and data revealed in Table 4, indicate the extent and nature of kernel damage. Broken corn and foreign matter (BCFM) is used in official market grading of corn. The overall BCFM sample means of .62, determined at Des Moines, and .55 determined at Iowa State Seed Lab, would not reduce market grade. Discrepancies in the BCFM percentages between the two determinations were not investigated. The Des Moines lab readings were made at field moisture, whereas the ISU lab readings were made on air dry corn.

BCFM less than whole kernel size was used as an index in analyzing kernel damage by analysis of variance and by regression calculations. BCFM less than whole kernel size is the combination of percentage of BCFM from the ISU Seed Lab, plus the percentage of broken corn over 12/64th inch and less than whole kernel size. Simulated handling of the corn produced 4.96 percent BCFM which would require screening to maintain No. 2 grade corn. Generally corn quality appeared high with the exception of a low 33.46 percent sound kernels, and a high 61.35 percentage whole kernels with damaged pericarp.
Table 4. Means and standard deviations for dependent variables, kernel damage

<table>
<thead>
<tr>
<th>Variables</th>
<th>Means</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>BCFM&lt;sup&gt;a&lt;/sup&gt;, official grade info., %</td>
<td>0.62</td>
<td>0.52</td>
</tr>
<tr>
<td>BCFM, ISU lab (&lt;12/64&quot;),%</td>
<td>0.55</td>
<td>0.42</td>
</tr>
<tr>
<td>BCFM less than whole kernel size,%</td>
<td>5.19</td>
<td>1.90</td>
</tr>
<tr>
<td>Broken corn, over 12/64&quot; and less than whole kernel, %</td>
<td>4.64</td>
<td>1.71</td>
</tr>
<tr>
<td>Whole kernel with damaged pericarp, %</td>
<td>61.35</td>
<td>14.62</td>
</tr>
<tr>
<td>Sound kernels&lt;sup&gt;b&lt;/sup&gt;, %</td>
<td>33.46</td>
<td>14.77</td>
</tr>
<tr>
<td>Germination, %</td>
<td>72.66</td>
<td>15.12</td>
</tr>
<tr>
<td>Simulated handling fines, %</td>
<td>4.96</td>
<td>2.42</td>
</tr>
</tbody>
</table>

<sup>a</sup>BCFM is broken corn less than 12/64th inch size and foreign matter.

<sup>b</sup>Sound kernels are kernels with no parts missing and no breaks in the seed coat.

Table 5. Main source of knowledge summary of 164 respondents

<table>
<thead>
<tr>
<th>Knowledge source</th>
<th>Frequency chosen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experience</td>
<td>143</td>
</tr>
<tr>
<td>Trained by experienced operator</td>
<td>20</td>
</tr>
<tr>
<td>Study machine manual</td>
<td>90</td>
</tr>
<tr>
<td>Educational meetings</td>
<td>20</td>
</tr>
<tr>
<td>Machinery dealers or service men</td>
<td>37</td>
</tr>
<tr>
<td>Magazine articles</td>
<td>23</td>
</tr>
</tbody>
</table>
The main sources of machine operating knowledge are presented in Table 5. The two main sources of knowledge indicated most frequently by machine operators were: (1) experience, by 89.2 percent of the respondents, and (2) study of the operators manual, by 54.9 percent.

The two least often indicated main sources of operating knowledge were: (1) educational meetings, and (2) trained by experienced operator, both indicated by 12.2 percent of the respondents. The item, machinery dealers or service men, was indicated by 22.6 percent of the respondents as a main source of knowledge. Magazine articles were declared important sources of knowledge by 14.0 percent of the respondents.

Correlations Between Harvesting and Damage Factors

The results of Pearson product-moment correlation calculations are presented in Tables 6 through 9.

Correlations between each independent variable and damaged whole kernels, and correlations between the same variables and sound kernels were near equal in magnitude but opposite in direction. The independent variables exhibited three significant correlations with broken corn and foreign matter, fines. Two of the correlated factors were agronomic, test weight (-.12) and corn variety (.18) (Table 6). The third was an operator variable, frequency of machine adjustment (-.19) (Table 7).
Table 6. Correlation of agronomic variables with measures of kernel damage

<table>
<thead>
<tr>
<th>Agronomic variables</th>
<th>Kernel damage measures</th>
<th>ISU BCFM</th>
<th>Broken corn +12/64&quot;</th>
<th>Damaged whole kernels</th>
<th>Sound kernels</th>
<th>Germ.</th>
<th>Simulated handling fines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test weight</td>
<td></td>
<td>-.12*</td>
<td>-.13*</td>
<td>.05</td>
<td>-.02</td>
<td>.38**</td>
<td>-.30**</td>
</tr>
<tr>
<td>Crop standability</td>
<td></td>
<td>.01</td>
<td>-.05</td>
<td>.02</td>
<td>-.02</td>
<td>-.15*</td>
<td>.00</td>
</tr>
<tr>
<td>Date of harvest</td>
<td></td>
<td>-.07</td>
<td>-.06</td>
<td>.10</td>
<td>-.09</td>
<td>-.27**</td>
<td>-.14**</td>
</tr>
<tr>
<td>Moisture content</td>
<td></td>
<td>.08</td>
<td>.07</td>
<td>-.06</td>
<td>.05</td>
<td>-.28**</td>
<td>.23**</td>
</tr>
<tr>
<td>Row spacing</td>
<td></td>
<td>.08</td>
<td>.04</td>
<td>.15*</td>
<td>-.15*</td>
<td>.05</td>
<td>.06</td>
</tr>
<tr>
<td>Varietya</td>
<td></td>
<td>.18*</td>
<td>.23**</td>
<td>-.07</td>
<td>.04</td>
<td>.10</td>
<td>.02</td>
</tr>
<tr>
<td>Yield per acre</td>
<td></td>
<td>.07</td>
<td>.05</td>
<td>-.11</td>
<td>.10</td>
<td>.14*</td>
<td>.01</td>
</tr>
</tbody>
</table>

* Significant beyond the five percent level.

** Significant beyond the one percent level.

a Variety was recoded using the mean breakage, less than whole kernel, as a numerical designation for that varietal grouping.
Table 7. Correlation of human variables with measures of kernel damage

<table>
<thead>
<tr>
<th>Human variables</th>
<th>Kernel damage measures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ISU BCFM Broken corn +12/64&quot; Damaged whole kernels Sound kernels Germ. Simulated handling fines</td>
</tr>
<tr>
<td>Age</td>
<td>.05 -.07 -.17* .17* .08 .08</td>
</tr>
<tr>
<td>Experience, years</td>
<td>.07 -.07 -.22** .23** -.03 -.01</td>
</tr>
<tr>
<td>Experience, acres/yr.</td>
<td>.12 .05 .00 -.01 .10 .05</td>
</tr>
<tr>
<td>Educ. general</td>
<td>.05 .14* -.04 .02 .01 .03</td>
</tr>
<tr>
<td>Years vo-ag h.s.</td>
<td>-.05 .08 .08 -.09 .01 .00</td>
</tr>
<tr>
<td>Post h.s. classes</td>
<td>-.15 .03 .07 -.06 .08 .10</td>
</tr>
<tr>
<td>Farming status^a</td>
<td>-.01 .07 -.01 .00 -.07 .10</td>
</tr>
<tr>
<td>Freq. machine adj.</td>
<td>-.19** -.04 .20** -.19** -.04 .01</td>
</tr>
<tr>
<td>Mechanical rating</td>
<td>-.03 -.06 .04 -.03 .12 -.08</td>
</tr>
<tr>
<td>Source of knowledge^a</td>
<td>.12 .19** .05 -.07 -.01 .10</td>
</tr>
</tbody>
</table>

* Significant beyond the five percent level.
** Significant beyond the one percent level.

^Each category of the variable was coded for correlation by using the mean kernel breakage less than whole kernel, as the group identification number.
Table 8. Correlation of machine operation variables with measures of kernel damage

<table>
<thead>
<tr>
<th>Variables</th>
<th>ISU BCFM</th>
<th>Broken corn</th>
<th>Damaged kernel</th>
<th>Sound kernel</th>
<th>Germ.</th>
<th>Simulated handling fines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combine make&lt;sup&gt;a&lt;/sup&gt;</td>
<td>.12</td>
<td>.26**</td>
<td>.18*</td>
<td>-.21**</td>
<td>-.04</td>
<td>.12</td>
</tr>
<tr>
<td>Cylinder, rpm</td>
<td>.05</td>
<td>.25**</td>
<td>-.08</td>
<td>.05</td>
<td>.10</td>
<td>.03</td>
</tr>
<tr>
<td>Cylinder, rpm adjusted</td>
<td>.01</td>
<td>.23**</td>
<td>-.10</td>
<td>.07</td>
<td>.18*</td>
<td>.04</td>
</tr>
<tr>
<td>Front cyl-conc. clearance</td>
<td>.06</td>
<td>-.01</td>
<td>-.02</td>
<td>.02</td>
<td>-.01</td>
<td>.03</td>
</tr>
<tr>
<td>Rear cyl-conc. clearance</td>
<td>.07</td>
<td>-.11</td>
<td>.22**</td>
<td>-.21*</td>
<td>-.04</td>
<td>-.12</td>
</tr>
<tr>
<td>Ground speed, mph</td>
<td>-.01</td>
<td>.09</td>
<td>.00</td>
<td>-.01</td>
<td>.03</td>
<td>-.06</td>
</tr>
<tr>
<td>Harvest rate, bu./hr.</td>
<td>-.04</td>
<td>.04</td>
<td>-.01</td>
<td>.01</td>
<td>.23**</td>
<td>.01</td>
</tr>
<tr>
<td>Harvest rate bu/cyl. in./10 hrs</td>
<td>.08</td>
<td>.16*</td>
<td>.07</td>
<td>-.09</td>
<td>.12</td>
<td>.13</td>
</tr>
<tr>
<td>Header size, rows</td>
<td>-.02</td>
<td>.04</td>
<td>-.11</td>
<td>.11</td>
<td>.22**</td>
<td>-.08</td>
</tr>
</tbody>
</table>

<sup>a</sup>Combine make groups were coded for correlation by using the mean kernel breakage less than whole kernel, as that group identification number.

* Significant beyond the five percent level.

** Significant beyond the one percent level.
Table 9. Correlations of kernel damage measures with kernel damage measures

<table>
<thead>
<tr>
<th>Kernel damage measures</th>
<th>ISU</th>
<th>Broken BCFM</th>
<th>Damaged whole</th>
<th>Sound kernel</th>
<th>Germ. Simulated handling fines</th>
</tr>
</thead>
<tbody>
<tr>
<td>BCFM, %, ISU</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Broken corn, +12/64&quot;, %</td>
<td>.36*</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Damaged whole kernels, %</td>
<td>.01</td>
<td>.02</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sound kernels, %</td>
<td>-.08</td>
<td>-.14**</td>
<td>-.99*</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Germination, %</td>
<td>-.07</td>
<td>-.12**</td>
<td>-.18*</td>
<td>.19*</td>
<td>1.00</td>
</tr>
<tr>
<td>Simulated handling fines, %</td>
<td>.32*</td>
<td>.33*</td>
<td>.12**</td>
<td>-.17*</td>
<td>-.17*</td>
</tr>
<tr>
<td>BCFM, %, official grade info.</td>
<td>.61*</td>
<td>.35*</td>
<td>.07</td>
<td>-.12**</td>
<td>-.04</td>
</tr>
<tr>
<td>Kernel damage and heat damage&lt;sup&gt;a&lt;/sup&gt;</td>
<td>.15**</td>
<td>.14**</td>
<td>.12**</td>
<td>-.14**</td>
<td>-.27*</td>
</tr>
</tbody>
</table>

*Significant beyond the five percent level.

**Significant beyond the one percent level.

<sup>a</sup>Nonmachine damage caused by environment.
The largest number of significant correlations between independent variables and measures of kernel damage occurred with broken corn over 12/64 inch, less than whole kernel size, and with germination. Four of the eight significant correlations with broken corn over 12/64th inch, presented in Table 8, were with machine operation variables, combine make (.26), cylinder revolutions per minute (.25), adjusted cylinder speed (.23), and harvest rate in bushels per cylinder inch (.16). The remaining four items correlated with broken corn over 12/64th inch size were: (1) corn test weight, -.13; and (2) corn variety, .23, indicated in Table 6; (3) general education, .14; and (4) source of knowledge, .19 presented in Table 7.

Agronomic variables accounted for 5 of the 8 significant correlations with germination. The five significantly correlated agronomic variables revealed in Table 6 were: (1) test weight (.38), (2) crop standability (-.15), (3) date of harvest (-.27), (4) moisture content (-.28), and (5) yield per acre (.14). Three additional significant correlations with germination were: (1) adjusted cylinder speed (.18), (2) harvest rate in bushel per hour (.23), and (3) combine header size (.22). These are reported in Table 8.

Damaged whole kernels and sound kernels each had six significant correlations with independent variables. Human or operator variables accounted for 3 of the above noted 6 correlations (Table 7). The three human variables were
age, experience and frequency of machine adjustment.

The independent variables significantly correlated with
whole damaged kernels were: (1) row spacing, .15; (2) operator
age, -.17; (3) years of experience, -.22; (4) frequency of
machine adjustment, .20; (5) combine make, .18; and (6) rear
cylinder-concave clearance, .22. A comparison of whole kernel
and sound kernel correlations with harvest variables in Tables
6 through 8 reveal opposite and near equal correlation values.

The simulated handling test results were significantly
correlated with test weight (-.30), date of harvest (-.14),
and moisture content (.23) (Table 6).

Of the 34 significant correlations between kernel damage
measures and independent variables, agronomic variables ac­
counted for 14, machine operation accounted for 11, and
human variables accounted for the remaining 9 correlations.

In Table 9 is a correlation matrix for dependent or
kernel damage measures. A near perfect, opposite correlation
existed between sound kernels and damaged whole kernels. The
Iowa State University Seed Laboratory determined broken corn
and foreign matter content, ISU BCFM, was significantly
correlated with (1) broken corn over 12/64th inch, .36;
(2) simulated handling fines, .32; (3) the official grade
BCFM, .61; and (4) kernel damage and heat damage levels, .15.

Damaged whole kernel data was not significantly
correlated with BCFM, nor with broken corn over 12/64th inch
size. Germination was significantly correlated with all dependent variables except BCFM. The simulated handling test results were correlated significantly with all corn damage variables as was the percent of kernel and heat damage.

Kernel Breakage by Harvest Factor Damage Analysis

Two measures of kernel damage, (1) percentage broken corn of less than whole kernel size, or broken corn, and (2) percentage BCFM after simulated handling, or fines, were chosen as measures of harvest kernel damage by which the effects of variations within each harvest factor were analyzed. Two null hypotheses were tested by single classification analysis of variance F-values for each harvest factor. The general form of the hypotheses were:

$H_{o1}$: There were no significant differences in mean kernel damage among groupings within the response interval for each harvesting factor variable measured,

$H_{o2}$: There was no significant difference between the mean kernel damage for respondents and for non-respondents to specific factor questions.

$H_{o1}$ and $H_{o2}$ were not tested as such but the specific null hypotheses for each variable were proposed and tested.

The mean corn damage for corn varietal groupings are presented in Table 10.
Table 10. Means and F-values for corn damage categorized by variety for single classification analysis of variance

<table>
<thead>
<tr>
<th>Corn variety</th>
<th>Percentage broken corn less than whole kernel</th>
<th>Percentage fines after simulated handling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
</tr>
<tr>
<td>DeKalb XL 45</td>
<td>8</td>
<td>5.69</td>
</tr>
<tr>
<td>DeKalb XL 45A</td>
<td>10</td>
<td>4.49</td>
</tr>
<tr>
<td>DeKalb 66</td>
<td>11</td>
<td>5.68</td>
</tr>
<tr>
<td>DeKalb 347</td>
<td>6</td>
<td>5.58</td>
</tr>
<tr>
<td>Funks 4444</td>
<td>10</td>
<td>4.85</td>
</tr>
<tr>
<td>Funks (other)</td>
<td>9</td>
<td>4.08</td>
</tr>
<tr>
<td>Pioneer 3570</td>
<td>9</td>
<td>5.13</td>
</tr>
<tr>
<td>Pioneer 3387</td>
<td>7</td>
<td>5.95</td>
</tr>
<tr>
<td>Pioneer 3390</td>
<td>6</td>
<td>5.26</td>
</tr>
<tr>
<td>Pioneer (other)</td>
<td>17</td>
<td>5.21</td>
</tr>
<tr>
<td>Misc. brands</td>
<td>47</td>
<td>4.96</td>
</tr>
<tr>
<td>Respondents</td>
<td>140</td>
<td>5.09</td>
</tr>
<tr>
<td>Nonrespondents</td>
<td>69</td>
<td>5.38</td>
</tr>
<tr>
<td>Sample</td>
<td>209</td>
<td>5.19</td>
</tr>
</tbody>
</table>
$H_{03}$: There was no significant difference between mean kernel damage of groups categorized by corn variety.

$H_{04}$: There was no significant difference between mean kernel damage for respondents and nonrespondents to the corn variety question.

The variation in percentage of broken corn was .87 among varietal groupings. A nonsignificant F-statistic of 0.872 was obtained. Mean percentage fines following the simulated handling test, revealed variations from a minimum of 4.04 percent fines for Pioneer 3570 to a maximum percentage of fines of 8.78 for Pioneer 3390. An F-value of 1.790 was not significant at the .05 level. The comparison of mean kernel damage for respondents and nonrespondents to the corn variety question revealed the percentage broken corn at 5.09 for respondents and at 5.38 for nonrespondents. The F-value of 1.087 was not statistically significant. The respondent - nonrespondent comparison of the simulated handling test results revealed a difference of .12 percent fines and yielded an F-value of 0.381.

Data presented in Table 10 are not sufficient to reject the specific null hypotheses $H_{03}$ and $H_{04}$. There were no significant differences in harvest damage.

Table 11 contains mean corn damage data categorized by harvest date. Harvest dates varied from October 3rd to December 14th.
<table>
<thead>
<tr>
<th>Harvest date</th>
<th>Percentage broken corn less than whole kernel</th>
<th>Percentage fines after simulated handling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
</tr>
<tr>
<td>Oct. 3-19</td>
<td>40</td>
<td>5.52</td>
</tr>
<tr>
<td>20-26</td>
<td>34</td>
<td>5.32</td>
</tr>
<tr>
<td>27-1</td>
<td>37</td>
<td>5.15</td>
</tr>
<tr>
<td>Nov. 2-8</td>
<td>36</td>
<td>5.19</td>
</tr>
<tr>
<td>9-15</td>
<td>10</td>
<td>4.98</td>
</tr>
<tr>
<td>16-22</td>
<td>11</td>
<td>4.73</td>
</tr>
<tr>
<td>21-29</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>30-6</td>
<td>12</td>
<td>4.87</td>
</tr>
<tr>
<td>Dec. 7-14</td>
<td>16</td>
<td>5.01</td>
</tr>
<tr>
<td>Respondents</td>
<td>195</td>
<td>5.20</td>
</tr>
<tr>
<td>Nonrespondents</td>
<td>14</td>
<td>4.95</td>
</tr>
<tr>
<td>Samples</td>
<td>209</td>
<td>5.19</td>
</tr>
</tbody>
</table>
Table 12. Means and F-values for corn damage categorized by grain moisture content for single classification analysis of variance

<table>
<thead>
<tr>
<th>Moisture percent</th>
<th>Percentage broken corn less than whole kernel</th>
<th>Percentage fines after simulated handling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
</tr>
<tr>
<td>17-17.9</td>
<td>3</td>
<td>6.66</td>
</tr>
<tr>
<td>18-18.9</td>
<td>9</td>
<td>6.09</td>
</tr>
<tr>
<td>19-19.9</td>
<td>11</td>
<td>4.97</td>
</tr>
<tr>
<td>20-20.9</td>
<td>23</td>
<td>4.48</td>
</tr>
<tr>
<td>21-21.9</td>
<td>45</td>
<td>5.12</td>
</tr>
<tr>
<td>22-22.9</td>
<td>54</td>
<td>5.03</td>
</tr>
<tr>
<td>23-23.9</td>
<td>32</td>
<td>5.19</td>
</tr>
<tr>
<td>24-24.9</td>
<td>15</td>
<td>5.57</td>
</tr>
<tr>
<td>25-25.9</td>
<td>7</td>
<td>5.97</td>
</tr>
<tr>
<td>26-26.9</td>
<td>7</td>
<td>6.27</td>
</tr>
<tr>
<td>27-27.9</td>
<td>2</td>
<td>5.99</td>
</tr>
</tbody>
</table>

Samples 208 5.20 202 4.93

*Significant beyond the five percent level.
**$H_0_5$:** There were no significant differences in mean kernel damage among groups categorized by harvest date.

**$H_0_6$:** There was no significant difference in mean kernel breakage measures for respondents and non-respondents to the harvest date question.

Kernel damage appeared to decrease from start to end of the harvest season. The decrease in mean damage over time was small, 5.52 to 5.01, for broken corn, and moderate, 5.20 to 3.83 percentage, for fines. The results on Table 11 indicated no statistically significant F-values therefore $H_0_5$ and $H_0_6$ were not rejected.

Kernel moisture content had been cited as an important factor influencing kernel breakage during combine harvesting of corn. Table 12 contains data concerning the relationship between kernel damage and percentage of moisture at harvest.

**$H_0_7$:** There were no significant differences in mean kernel damage among samples grouped by moisture content at harvest time.

The percentages of corn breakage were higher at the low, 17 to 17.9 and at the high, 27 to 27.9 percent moisture levels, 5.99 to 5.19, respectively. The simulated handling test resulted in increased BCFM with increased moisture content at harvest time. The low mean of 3.99 percent fines was for the 18-18.9 percent moisture category whereas, a high of 8.46 percent fines was found for the 26-26.9
Table 13. Means and F-values for corn damage categorized by test weight per bushel for single classification analysis of variance

<table>
<thead>
<tr>
<th>Pounds test weight</th>
<th>Percentage broken corn less than whole kernel N</th>
<th>Mean</th>
<th>F</th>
<th>Percentage fines after simulated handling N</th>
<th>Mean</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 51</td>
<td>6</td>
<td>4.69</td>
<td></td>
<td>6</td>
<td>7.98</td>
<td></td>
</tr>
<tr>
<td>51-51.9</td>
<td>11</td>
<td>6.56</td>
<td></td>
<td>11</td>
<td>6.50</td>
<td></td>
</tr>
<tr>
<td>52-52.9</td>
<td>12</td>
<td>5.31</td>
<td></td>
<td>11</td>
<td>5.36</td>
<td></td>
</tr>
<tr>
<td>53-53.9</td>
<td>41</td>
<td>5.44</td>
<td></td>
<td>41</td>
<td>5.29</td>
<td></td>
</tr>
<tr>
<td>54-54.9</td>
<td>58</td>
<td>5.21</td>
<td>1.5560</td>
<td>56</td>
<td>4.73</td>
<td>3.3103*</td>
</tr>
<tr>
<td>55-55.9</td>
<td>40</td>
<td>5.16</td>
<td></td>
<td>40</td>
<td>4.81</td>
<td></td>
</tr>
<tr>
<td>56-56.9</td>
<td>29</td>
<td>4.67</td>
<td></td>
<td>27</td>
<td>4.19</td>
<td></td>
</tr>
<tr>
<td>57-57.9</td>
<td>9</td>
<td>4.24</td>
<td></td>
<td>8</td>
<td>3.12</td>
<td></td>
</tr>
<tr>
<td>58-59</td>
<td>2</td>
<td>6.38</td>
<td></td>
<td>2</td>
<td>2.60</td>
<td></td>
</tr>
</tbody>
</table>

Samples: 208 (Kernel damage) 202 (Percentage fines after simulated handling)

*Significant beyond the one percent level.

percent moisture category. A more typical spread in percentage of fines from low to high moisture levels was 3.99 percent at 18-18.9 percent moisture to 5.40 percent fines at 27-27.9 percent moisture. A significant F-statistic (2.2907) was computed from the simulated handling test results for the mean percentages of fines of samples categorized by moisture content. $H_0$ was rejected because
mean kernel damage variance as measured by the percentage of fines yielded a significant F-statistic.

Kernel damage of corn categorized by variation in test weight per bushel is presented in Table 13.

\[ \text{Ho}_8: \text{There was no significant difference among group means for kernel damage of samples categorized by test weight.} \]

Test weight varied from less than 51 pounds per bushel for six corn samples to 58 pounds per bushel for two corn samples. The modal test weight category was 54-54.9 pounds per bushel and included 58, or 27.9 percent, of the samples. A decrease in percentage of fines from the handling test occurred with increased corn test weight. The group damage means for corn categorized by test weight varied from 2.60 percent fines for corn weighing 58 to 59 pounds per bushel, to 7.98 percent fines for corn weighing less than 51 pounds per bushel. A highly significant F-statistic (3.310) resulted from analysis of the fines means data. The null hypothesis was rejected. A highly significant difference between means of fines, kernel damage, was noted for the test weight categories.

The mean measures of corn damage for row spacing groups, and for respondents and nonrespondents to the row spacing question, are included in Table 14.

\[ \text{Ho}_9: \text{There were no significant differences among mean kernel damage percentages for samples grouped by row spacing.} \]
Table 14. Means and F-values for corn damage categorized by row spacing for single classification analysis of variance

<table>
<thead>
<tr>
<th>Row spacing, inches</th>
<th>Percentage broken corn less than whole kernel</th>
<th>Percentage fines after simulated handling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
</tr>
<tr>
<td>28-30</td>
<td>34</td>
<td>5.08</td>
</tr>
<tr>
<td>36</td>
<td>10</td>
<td>4.72</td>
</tr>
<tr>
<td>38</td>
<td>112</td>
<td>5.19</td>
</tr>
<tr>
<td>40</td>
<td>14</td>
<td>5.78</td>
</tr>
</tbody>
</table>

Respondents 170
Nonrespondents 39

Samples 209

$H_{0}^{10}$: There was no significant difference between kernel damage means for corn grouped by respondent and nonrespondent to the row space question.

The broken corn percentage varied from 4.72 to 5.78 around a grand mean of 5.19 percent. The highest percentage of damage was with 40 inch rows, the lowest with the 36 inch row spacing. The percentage of fines after simulated handling fluctuated about the mean of 4.93 from 4.70 percent fines in 28-30 inch row corn to 5.82 percent for 36 inch row corn. The null hypotheses were not rejected. F-values in Table 14, for row spacing data, indicate no
significant differences in damage among corn samples stratified by row space.

The amount of lodging in the corn crop was rated by three levels of standability.

\( H_{01} \): There were no significant differences among corn damage means for samples categorized by corn standability.

\( H_{02} \): There was no significant difference between kernel damage means for respondents and non-respondents to the standability question.

Information in Table 15 indicates more lodging resulted in less kernel damage. The over 25 percent lodged group

<table>
<thead>
<tr>
<th>Table 15. Means and F-values for corn damage categorized by corn standability for single classification analysis of variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standability</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Mostly upright</td>
</tr>
<tr>
<td>Some lodging</td>
</tr>
<tr>
<td>Over 25% lodged</td>
</tr>
<tr>
<td>Respondents</td>
</tr>
<tr>
<td>Non-respondents</td>
</tr>
<tr>
<td>Samples</td>
</tr>
</tbody>
</table>

*Significant beyond the five percent level.
had the lowest level of both broken corn and fines, 4.38 and 4.33 respectively compared to overall means of 5.19 and 4.93. Respondents and nonrespondents supplied samples with near equal percentages of broken corn. The non-respondent grouping had slightly less fines (.50 percent less) than the respondent grouping.

The analysis of variance for broken corn means and degree of lodging yielded a significant F-value of 3.063. Ho₁₁ was rejected. Ho₁₂ was not rejected. There were differences in corn damage among samples categorized by standability. There were no significant differences between respondents and nonrespondents in corn damage.

Table 16 contains the yield categories from 53 to 157 bushels per acre, the response frequency for each group, the mean damage factor and F-statistics calculated by single classification analysis of variance.

Ho₁₃: There was no significant difference between corn damage means of samples grouped by yield per acre.

Ho₁₄: There was no significant difference between mean corn damage for respondents and non-respondents to the yield question.

Damage increased with increased yield except for the high and for the low yield categories. The high yield had low damage and the low yield had high damage. The most common yield category, 98-112 bushel per acre, had a mean
Table 16. Means and F-values for corn damage categorized by yield per acre for single classification analysis of variance

<table>
<thead>
<tr>
<th>Bushels per acre</th>
<th>Percentage broken corn less than whole kernel</th>
<th>Percentage fines after simulated handling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
</tr>
<tr>
<td>53-67</td>
<td>2</td>
<td>7.77</td>
</tr>
<tr>
<td>68-82</td>
<td>8</td>
<td>4.08</td>
</tr>
<tr>
<td>83-97</td>
<td>19</td>
<td>4.76</td>
</tr>
<tr>
<td>98-112</td>
<td>59</td>
<td>5.16</td>
</tr>
<tr>
<td>113-127</td>
<td>41</td>
<td>5.44</td>
</tr>
<tr>
<td>128-142</td>
<td>25</td>
<td>5.82</td>
</tr>
<tr>
<td>143-157</td>
<td>4</td>
<td>3.77</td>
</tr>
<tr>
<td>Respondents</td>
<td>158</td>
<td>5.23</td>
</tr>
<tr>
<td>Nonrespondents</td>
<td>51</td>
<td>5.05</td>
</tr>
<tr>
<td>Samples</td>
<td>209</td>
<td>5.19</td>
</tr>
</tbody>
</table>

Kernel damage similar to the overall mean kernel damage, 5.16 compared to a mean of 5.19 percent for broken corn, and a mean of 4.88 compared to a mean of 4.93 for percentage of fines. Respondents had .18 percentage more broken corn and .59 percentage more fines than nonrespondents. The F-values for percentage of corn breakage and fines categorized by yield per acre were not significantly large.
Ho_{13} and Ho_{14} were not rejected. No significant differences in corn damage due to yield or response to yield question were found.

Harvest machine operators were categorized according to farming status. The comparative performance of the groups of operators are presented in Table 17.

Ho_{15}: There were no significant differences among kernel damage means for operators grouped by farming status.

Ho_{16}: There was no significant difference between the mean kernel damage for farming status question respondents and nonrespondents.

Hired operators had the lowest kernel damage rate, 4.68 percent broken corn and 4.14 percent fines. The highest kernel damage, 5.20 percent broken corn and 5.14 percent fines was produced by the owner-operators. Respondent - nonrespondent comparisons indicate respondents had the lower percentage of broken corn but were high in percentage of fines produced. The F-values resulting from the analysis of data in Table 17 provide no basis for rejecting null hypotheses Ho_{15} and Ho_{16}. No significant differences were found in corn damage when operators were classified by farming status or respondents questionnaire item.

Means for corn damage of groupings based on machine adjustment frequency per day and by response - nonresponse grouping are presented in Table 18.
Table 17. Means and F-values for corn damage categorized by farming status of machine operators for single classification analysis of variance

<table>
<thead>
<tr>
<th>Operator status</th>
<th>Percentage broken corn less than whole kernel</th>
<th>Percentage fines after simulated handling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
</tr>
<tr>
<td>Farmers operator</td>
<td>127</td>
<td>5.20</td>
</tr>
<tr>
<td>Hired operator</td>
<td>9</td>
<td>4.68</td>
</tr>
<tr>
<td>Custom operator</td>
<td>20</td>
<td>5.13</td>
</tr>
<tr>
<td>Respondents</td>
<td>156</td>
<td>5.16</td>
</tr>
<tr>
<td>Nonrespondents</td>
<td>53</td>
<td>5.26</td>
</tr>
<tr>
<td>Samples</td>
<td>209</td>
<td>5.19</td>
</tr>
</tbody>
</table>

Table 18. Means and F-values for corn damage categorized by frequency of machine adjustment for single classification analysis of variance

<table>
<thead>
<tr>
<th>Adjustments per day</th>
<th>Percentage broken corn less than whole kernel</th>
<th>Percentage fines after simulated handling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
</tr>
<tr>
<td>One</td>
<td>34</td>
<td>4.92</td>
</tr>
<tr>
<td>Two</td>
<td>46</td>
<td>5.78</td>
</tr>
<tr>
<td>Three</td>
<td>20</td>
<td>5.25</td>
</tr>
<tr>
<td>Several</td>
<td>57</td>
<td>4.88</td>
</tr>
<tr>
<td>Respondents</td>
<td>157</td>
<td>5.20</td>
</tr>
<tr>
<td>Nonrespondents</td>
<td>52</td>
<td>5.15</td>
</tr>
<tr>
<td>Samples</td>
<td>209</td>
<td>5.19</td>
</tr>
</tbody>
</table>
$H_{0_{17}}$: There were no significant differences in mean kernel damage among groupings based on machine adjustment frequency.

$H_{0_{18}}$: There was no significant difference in mean kernel damage between respondents and non-respondents to the adjustment frequency question.

The most frequent adjustment rate, several times per day, was indicated by 36.3 percent of the respondents. One and two adjustments per day were indicated by 21.7 and by 29.3 percent, respectively, of the responding operators. Three adjustments per day was the least frequent adjustment rate indicated.

No pattern of kernel damage is evident from data in Table 18. The failure of F-values to reach the level of significance chosen for rejection of the null hypotheses indicates that any variations in means in Table 18 were probably due to chance variation and not associated with machine adjustment frequency. $H_{0_{17}}$ and $H_{0_{18}}$ were not rejected.

Mechanical interest and ability ratings for machine operators and resulting corn damage percentages are provided in Table 19.

$H_{0_{19}}$: There were no significant differences in mean kernel damage among operators grouped by mechanical interest and ability.

$H_{0_{20}}$: There was no significant difference in kernel damage means between respondent and nonrespondent classification.
Table 19. Means and F-values for corn damage categorized by rated mechanical interest and ability for single classification analysis of variance

<table>
<thead>
<tr>
<th>Mechanical interest and ability</th>
<th>Percentage broken corn less than whole kernel</th>
<th>Percentage fines after simulated handling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
</tr>
<tr>
<td>Low</td>
<td>1</td>
<td>7.29</td>
</tr>
<tr>
<td>Medium</td>
<td>93</td>
<td>5.28</td>
</tr>
<tr>
<td>High</td>
<td>65</td>
<td>5.12</td>
</tr>
<tr>
<td>Respondents</td>
<td>159</td>
<td>5.23</td>
</tr>
<tr>
<td>Nonrespondents</td>
<td>50</td>
<td>5.06</td>
</tr>
<tr>
<td>Samples</td>
<td>209</td>
<td>5.19</td>
</tr>
</tbody>
</table>

The most frequent self rating was medium ability, 58.5 percent of respondents. A high rating was indicated by 40.9 percent of the respondents. Only one person rated himself low in mechanical interest and ability. The low rated operator had the high percentage of damage. Operators who rated themselves high had lower rates of corn damage. A trend appeared to be evident, but it was not statistically proven. The null hypotheses were not rejected. Self rating scores on mechanical interest and ability were not statistically associated with harvest kernel damage.

Machine operator age and kernel damage comparisons are
presented in Table 20.

Table 20. Means and F-values for corn damage categorized by machine operator age for single classification analysis of variance

<table>
<thead>
<tr>
<th>Years of age</th>
<th>Percentage broken corn less than whole kernel</th>
<th>Percentage fines after simulated handling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
</tr>
<tr>
<td>less than 25</td>
<td>7</td>
<td>5.50</td>
</tr>
<tr>
<td>25-34</td>
<td>37</td>
<td>5.20</td>
</tr>
<tr>
<td>35-44</td>
<td>48</td>
<td>5.22</td>
</tr>
<tr>
<td>45-54</td>
<td>46</td>
<td>5.22</td>
</tr>
<tr>
<td>55-64</td>
<td>25</td>
<td>4.98</td>
</tr>
<tr>
<td>65 and over</td>
<td>4</td>
<td>4.63</td>
</tr>
<tr>
<td>Respondents</td>
<td>167</td>
<td>5.18</td>
</tr>
<tr>
<td>Nonrespondents</td>
<td>42</td>
<td>5.22</td>
</tr>
<tr>
<td>Samples</td>
<td>209</td>
<td>5.19</td>
</tr>
</tbody>
</table>

$H_{01}$: There were no significant differences in means for kernel damage among groups classified by age.

$H_{02}$: There was no significant difference in mean kernel damage between respondents and non-respondents.

The ages of operators appeared to be normally distributed, 56.3 percent of the operators were between 35 and 54 years of age. The widest spread among kernel damage means among age classifications were 0.87 percent for broken corn
and 1.14 percent for fines. Broken corn percentages decreased with age, fines did not show a pattern. Respondents and nonrespondents performed near the mean for broken corn percentages. Nonrespondents had .46 percent less fines than respondents. No significant F-values were produced by analysis of variance. \( \text{Ho}_{21} \) and \( \text{Ho}_{22} \) were not rejected.

A comparison of mean kernel damage of operators grouped by specific source of knowledge is found in Table 21.

\( \text{Ho}_{23} \): There were no significant differences in mean kernel damage among operators grouped by main source of knowledge.

\( \text{Ho}_{24} \): There was no significant difference in mean kernel damage between respondent and nonrespondent groups.

Six sources of knowledge were listed for operator response. Mean percentage broken corn varied .95 percent from low to high and mean percent fines varied by 1.37 percentage points among the six knowledge source categories. Operators grouped by a specific source of knowledge generally had higher percentages of damage than did the comparative remaining operators.

Combinations of sources of knowledge indicated by machine operators are revealed in Table 22. A difference of 2.05 percent broken corn existed between the highest and lowest damage groups. The high damage group used experience, manual, and dealer knowledge as sources, whereas, the low
Table 21. Means and F-values for corn damage categorized by source of operating knowledge for single classification analysis of variance

<table>
<thead>
<tr>
<th>Source of knowledge</th>
<th>Percentage broken corn less than whole kernel</th>
<th>Percentage fines after simulated handling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
</tr>
<tr>
<td>Experience</td>
<td>143</td>
<td>5.24</td>
</tr>
<tr>
<td>All other samples</td>
<td>66</td>
<td>5.07</td>
</tr>
<tr>
<td>Trained by exp. operator</td>
<td>20</td>
<td>4.53</td>
</tr>
<tr>
<td>All other samples</td>
<td>189</td>
<td>5.26</td>
</tr>
<tr>
<td>Study op. manual</td>
<td>90</td>
<td>5.28</td>
</tr>
<tr>
<td>All other samples</td>
<td>119</td>
<td>5.12</td>
</tr>
<tr>
<td>Educational meetings</td>
<td>20</td>
<td>5.02</td>
</tr>
<tr>
<td>All other samples</td>
<td>189</td>
<td>5.20</td>
</tr>
<tr>
<td>Machinery dealers</td>
<td>37</td>
<td>5.48</td>
</tr>
<tr>
<td>All other samples</td>
<td>172</td>
<td>5.12</td>
</tr>
<tr>
<td>Magazine articles</td>
<td>23</td>
<td>5.37</td>
</tr>
<tr>
<td>All other samples</td>
<td>186</td>
<td>5.16</td>
</tr>
</tbody>
</table>
Table 22. Means and F-values for corn damage categorized by sources of operating knowledge for single classification analysis of variance

<table>
<thead>
<tr>
<th>Sources of knowledge</th>
<th>Percentage broken corn less than whole kernel</th>
<th>Percentage fines after simulated handling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
</tr>
<tr>
<td>Experience, only</td>
<td>56</td>
<td>5.12</td>
</tr>
<tr>
<td>Trained by exp. op.</td>
<td>8</td>
<td>4.50</td>
</tr>
<tr>
<td>Exp. and op. manual</td>
<td>38</td>
<td>5.22</td>
</tr>
<tr>
<td>Exp., man., educ., dealer</td>
<td>5</td>
<td>5.13</td>
</tr>
<tr>
<td>Exp., man., magazines</td>
<td>6</td>
<td>5.97</td>
</tr>
<tr>
<td>Exp., man., dealers</td>
<td>11</td>
<td>6.27</td>
</tr>
<tr>
<td>Exp., man., mag., dealer</td>
<td>5</td>
<td>4.22</td>
</tr>
<tr>
<td>Other combinations</td>
<td>35</td>
<td>5.22</td>
</tr>
<tr>
<td>Nonrespondents</td>
<td>45</td>
<td>5.08</td>
</tr>
<tr>
<td>Samples</td>
<td>209</td>
<td>5.19</td>
</tr>
</tbody>
</table>

damage group indicated experience, manual, magazine and dealer as the main sources. Analysis of variance treatment of the data in Tables 21 and 22 provided no F-values large enough to reject either Ho$^{23}$ or Ho$^{24}$. 
An analysis of variance for kernel damage means of operators grouped by years of formal education is presented in Table 23.

\( H_0_{25} \): There were no significant differences in mean kernel damage among operators grouped by years of schooling.

\( H_0_{26} \): There was no significant difference in mean kernel damage of respondent and nonrespondent operators.

Table 23. Means and F-values for corn damage categorized by highest grade schooling for single classification analysis of variance

<table>
<thead>
<tr>
<th>Grade of schooling</th>
<th>Percentage broken corn less than whole kernel</th>
<th>Percentage fines after simulated handling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
</tr>
<tr>
<td>8</td>
<td>16</td>
<td>4.34</td>
</tr>
<tr>
<td>9</td>
<td>5</td>
<td>6.33</td>
</tr>
<tr>
<td>10 or 11</td>
<td>4</td>
<td>5.59</td>
</tr>
<tr>
<td>12</td>
<td>105</td>
<td>5.11</td>
</tr>
<tr>
<td>13</td>
<td>6</td>
<td>5.31</td>
</tr>
<tr>
<td>14</td>
<td>6</td>
<td>4.75</td>
</tr>
<tr>
<td>15 or more</td>
<td>8</td>
<td>6.22</td>
</tr>
<tr>
<td>Respondents</td>
<td>150</td>
<td>5.13</td>
</tr>
<tr>
<td>Nonrespondents</td>
<td>59</td>
<td>5.32</td>
</tr>
<tr>
<td>Samples</td>
<td>209</td>
<td>5.19</td>
</tr>
</tbody>
</table>
Years of schooling completed was categorized into 7 groups, from 8 years to 15 or more years; 10 and 11 years were grouped as one. Most of the respondents, 70.0 percent, had 12 years of schooling; 16.7 percent had less than 12 years; and 13.3 percent had over 12 years of formal education. The mean percentage of broken corn for all samples was 5.19 percent. The group with nine years of schooling had 6.33 percent of broken corn, and the group with 15 or more years schooling had 6.22 percent of broken corn. Damage trended lower with increased education from 9 to 14 years. The lowest mean percentage of broken corn was for the 8 years of schooling group. Percentages of broken corn for the respondents and nonrespondents were near the mean, 5.13 and 5.32 percent respectively. Percentage of fines resulting from the handling test revealed a 1.37 percent variation. The low was 3.70 percent for the 14-year group and the high was 5.07 percent by the 12-year group. The F-values resulting from analysis of variance tests were not significant. The null hypotheses were not rejected.

Corn damage data were also grouped by years of high school vo-ag completed by the operators. The groupings, data and F-values are presented in Table 24.
Table 24. Means and F-values for corn damage categorized by years of high school vocational agriculture enrollment for single classification analysis of variance

<table>
<thead>
<tr>
<th>Years vo-ag</th>
<th>Percentage broken corn less than whole kernel</th>
<th>Percentage fines after simulated handling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
</tr>
<tr>
<td>0</td>
<td>50</td>
<td>4.76</td>
</tr>
<tr>
<td>1</td>
<td>10</td>
<td>5.05</td>
</tr>
<tr>
<td>2</td>
<td>13</td>
<td>4.72</td>
</tr>
<tr>
<td>3</td>
<td>14</td>
<td>5.06</td>
</tr>
<tr>
<td>4</td>
<td>24</td>
<td>4.99</td>
</tr>
<tr>
<td>Respondents</td>
<td>111</td>
<td>4.87</td>
</tr>
<tr>
<td>Nonrespondents</td>
<td>98</td>
<td>5.55</td>
</tr>
<tr>
<td>Samples</td>
<td>209</td>
<td>5.19</td>
</tr>
</tbody>
</table>

**Significant beyond the one percent level.

Ho$_{27}$: There were no significant differences in mean kernel damage among groups with differing levels of vo-ag backgrounds.

Ho$_{28}$: There was no significant difference in mean kernel damage of respondents and nonrespondents to the vo-ag instruction question.

The number of respondents to the vo-ag question was lower than for most other questions; of the 111 respondents, 45.0 percent reported zero vo-ag, whereas, 21.6 percent reported 4 years of vo-ag in high school. Ho$_{27}$ was not
rejected. Nonsignificant F-values of 0.196 and 0.064 were obtained. No association was evident between the amount of vo-ag completed and kernel damage. $H_0^{28}$ was rejected due to a significant F-value of 6.79 for respondent - non-respondent broken corn analysis. Respondents to the question concerning vo-ag enrollment in high school had less broken corn as indicated by a mean of 4.87 percent broken corn compared to 5.55 percent for nonrespondents. The difference in mean damage was not only evident but statistically significant.

Operator participation in post-high school vo-ag classes and kernel damage comparisons are presented in Table 25.

$H_0^{29}$: There were no significant differences in mean kernel damage among groups categorized by type of post high school vo-ag class membership.

Adult and young farmer class participation was indicated by 14.4 percent of the respondent combine operators. Young farmer class members had the least broken corn, 3.79 percent, whereas, the adult farmer class participants had the least percentage of fines, 4.32 percent. Respondents and nonrespondents data in Table 25 is identical to that presented in Table 24 as all vo-ag response categories were derived from one question. The F-value for class membership comparisons was not sufficient to reject the null hypothesis at the five percent level of significance.
Table 25. Means and F-values for corn damage categorized by young or adult farmer vo-ag class attendance for single classification analysis of variance

<table>
<thead>
<tr>
<th>Post high school vo-ag classes</th>
<th>Kernel damage</th>
<th>Percentage fines after less than whole kernel simulated handling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
</tr>
<tr>
<td>None</td>
<td>95</td>
<td>4.91</td>
</tr>
<tr>
<td>Young farmer</td>
<td>6</td>
<td>3.79</td>
</tr>
<tr>
<td>Adult farmer</td>
<td>10</td>
<td>5.15</td>
</tr>
<tr>
<td>Respondents</td>
<td>111</td>
<td>4.87</td>
</tr>
<tr>
<td>Nonrespondents</td>
<td>98</td>
<td>5.55</td>
</tr>
<tr>
<td>Samples</td>
<td>209</td>
<td>5.19</td>
</tr>
</tbody>
</table>

*Significant beyond the one percent level.

Years of operator experience in combine harvesting varied from 11 men with one year of experience to 4 men with 31 or more years of experience.

$H_{030}$: There were no significant differences in mean kernel damage among groups categorized by operator experience.

$H_{031}$: There was no significant difference in mean kernel damage between respondents and non-respondents to the years of experience question.

The mode was 6 to 7 years of experience had by 36 operators. Mean kernel damage and F-values are presented in Table 26 for operators categorized by years of harvesting experience. Kernel damage means were quite low for the
Table 26. Means and F-values for corn damage categorized by years of combining experience for single classification analysis of variance

<table>
<thead>
<tr>
<th>Years of experience</th>
<th>Percentage broken corn less than whole kernel</th>
<th>Percentage fines after simulated handling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
</tr>
<tr>
<td>1</td>
<td>11</td>
<td>4.70</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>6.40</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>5.81</td>
</tr>
<tr>
<td>4</td>
<td>13</td>
<td>6.02</td>
</tr>
<tr>
<td>5</td>
<td>21</td>
<td>4.88</td>
</tr>
<tr>
<td>6-7</td>
<td>36</td>
<td>5.11</td>
</tr>
<tr>
<td>9-11</td>
<td>20</td>
<td>4.66</td>
</tr>
<tr>
<td>12-15</td>
<td>9</td>
<td>5.57</td>
</tr>
<tr>
<td>16-22</td>
<td>11</td>
<td>5.15</td>
</tr>
<tr>
<td>23-30</td>
<td>14</td>
<td>5.43</td>
</tr>
<tr>
<td>31 and over</td>
<td>4</td>
<td>4.01</td>
</tr>
<tr>
<td>Respondents</td>
<td>155</td>
<td>5.19</td>
</tr>
<tr>
<td>Nonrespondents</td>
<td>54</td>
<td>5.17</td>
</tr>
<tr>
<td>Samples</td>
<td>209</td>
<td>5.19</td>
</tr>
</tbody>
</table>

First year operators (4.70 and 4.66), but highest among all operator groups for second year operators (6.40 and 6.22). Damage percentages were quite consistent after two years of experience. No mean score variance was adequate,
as indicated by F-values, to reject the null hypotheses. Respondent and nonrespondent groups had results near the overall mean. No significant differences in means were observed among experience groups.

Combine operating experience in terms of acres harvested per year varied from less than 190 acres to over 1191 acres per year. The mean kernel damage, acres harvested annually, number of operators, and F-values are found in Table 27.

Table 27. Means and F-values for corn damage categorized by operator experience in acres per year for single classification analysis of variance

<table>
<thead>
<tr>
<th>Acres per year combined</th>
<th>N</th>
<th>Percentage broken corn less than whole kernel</th>
<th>Percentage fines after simulated handling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Percentage</td>
<td>N</td>
</tr>
<tr>
<td>Less than 190</td>
<td>19</td>
<td>5.30</td>
<td>17</td>
</tr>
<tr>
<td>191-390</td>
<td>39</td>
<td>5.10</td>
<td>38</td>
</tr>
<tr>
<td>391-490</td>
<td>14</td>
<td>5.61</td>
<td>13</td>
</tr>
<tr>
<td>491-590</td>
<td>16</td>
<td>4.19</td>
<td>15</td>
</tr>
<tr>
<td>591-890</td>
<td>27</td>
<td>4.81</td>
<td>26</td>
</tr>
<tr>
<td>891-1190</td>
<td>14</td>
<td>5.65</td>
<td>14</td>
</tr>
<tr>
<td>1191 and more</td>
<td>7</td>
<td>5.88</td>
<td>7</td>
</tr>
<tr>
<td>Respondents</td>
<td>136</td>
<td>5.11</td>
<td>130</td>
</tr>
<tr>
<td>Nonrespondents</td>
<td>73</td>
<td>5.33</td>
<td>72</td>
</tr>
<tr>
<td>Samples</td>
<td>209</td>
<td>5.19</td>
<td>202</td>
</tr>
</tbody>
</table>
There were no significant differences in mean kernel damage among operators categorized by acres of corn combining per year.

There was no significant difference in the mean kernel damage between respondents and non-respondents to the acres harvested question.

Acres harvested appeared bimodal with 39 operators indicating 191-390 acres per year, and 591-890 acres harvested per year indicated by 27 operators. Operators with 491 to 890 acres of combining experience per year had the least kernel damage (mean percentage of 4.67). Respondents (mean of 4.99) had slightly lower percentages of broken corn and fines than did nonrespondents (mean of 5.18). The null hypotheses were tested with the F-statistic and were not rejected. No significant kernel damage differences due to groupings by acres of corn harvest experience were found.

Operator and corn damage data categorized by machine make are provided in Table 28.

There were no significant differences in means for kernel damage among samples grouped by the machine make.

There was no significant difference between means for kernel damage of samples categorized by respondent status of the operator.

Below average damage was produced by picker-shellers (4.49), by Oliver (4.58) and New Idea combines (3.43). Above average damage was observed for Ford (6.86), Gleaner (5.87) and Massey-Ferguson combines (5.53). The mean
Table 28. Means and F-values for corn damage categorized by machine make for single classification analysis of variance

<table>
<thead>
<tr>
<th>Machine make</th>
<th>Kernel damage</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Percentage broken corn less than whole kernel</td>
<td>Percentage fines after simulated handling</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
<td>F</td>
</tr>
<tr>
<td>Case</td>
<td>9</td>
<td>5.31</td>
<td></td>
</tr>
<tr>
<td>Ford</td>
<td>1</td>
<td>6.86</td>
<td></td>
</tr>
<tr>
<td>Gleaner</td>
<td>27</td>
<td>5.87</td>
<td></td>
</tr>
<tr>
<td>International Harvester</td>
<td>30</td>
<td>4.70</td>
<td></td>
</tr>
<tr>
<td>John Deere</td>
<td>49</td>
<td>5.10</td>
<td></td>
</tr>
<tr>
<td>Massey-Ferguson</td>
<td>37</td>
<td>5.53</td>
<td>1.3487</td>
</tr>
<tr>
<td>New Idea</td>
<td>4</td>
<td>3.43</td>
<td></td>
</tr>
<tr>
<td>New Holland</td>
<td>1</td>
<td>5.56</td>
<td></td>
</tr>
<tr>
<td>Oliver</td>
<td>9</td>
<td>4.58</td>
<td></td>
</tr>
<tr>
<td>Picker sheller&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4</td>
<td>4.49</td>
<td></td>
</tr>
<tr>
<td>Respondents</td>
<td>171</td>
<td>5.19</td>
<td></td>
</tr>
<tr>
<td>Nonrespondents</td>
<td>38</td>
<td>5.18</td>
<td>0.0019</td>
</tr>
<tr>
<td>Samples</td>
<td>209</td>
<td>5.19</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>Other machines are combine units.
for all machines was 5.19 percent broken corn. Analysis of the data provided no statistical evidence to reject the two stated null hypotheses.

The most popular combine corn header size was four-row, as indicated in 50 percent of the responses. Two-row headers were used on 41.2 percent of the samples, 3 and 6-row headers accounted for 6.5 and 2.4 percent of the responses respectively. Table 29 contains information concerning header size of harvesting machine and kernel damage data.

\( H_{036} \): There were no significant difference among means when kernel damage was categorized by header size.

\( H_{037} \): There was no significant difference between means for kernel damage of respondents and non-respondents to the header size question.

Three- and six-row headers (4.40) had the lower means for kernel and fines than the two- (5.19) and four-row (5.17) headers. F-values produced from analysis of the data failed to reach the level needed to reject the null hypotheses proposed.

An analysis of data was made with sample information grouped according to harvester ground speed.

\( H_{038} \): There were no significant difference among group kernel damage means when results were categorized by harvester ground speed.

\( H_{039} \): There was no significant difference between means for kernel damage for respondent and non-respondents to the ground speed question.
Table 29. Means and F-values for corn damage categorized by rows per corn header for single classification analysis of variance

<table>
<thead>
<tr>
<th>Header size in rows</th>
<th>Percentage broken corn less than whole kernel</th>
<th>Percentage fines after simulated handling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
</tr>
<tr>
<td>2</td>
<td>70</td>
<td>5.13</td>
</tr>
<tr>
<td>4</td>
<td>85</td>
<td>5.29</td>
</tr>
<tr>
<td>3</td>
<td>11</td>
<td>4.92</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>4.93</td>
</tr>
<tr>
<td>Respondents</td>
<td>170</td>
<td>5.19</td>
</tr>
<tr>
<td>Non-respondents</td>
<td>39</td>
<td>5.17</td>
</tr>
<tr>
<td>Samples</td>
<td>209</td>
<td>5.19</td>
</tr>
</tbody>
</table>

The data in Table 30 reveal the results of grouping samples by ground speed at harvest. Modal ground speed was 2.6 to 3.0 miles per hour. Harvest speeds of less than 1 to 4.5 miles per hour were indicated. The broken corn damage means varied from 4.91 to 5.86 percent. Both high and low damage levels occurred at speeds above three miles per hour. The percentage of fines displayed extremes in damage at the upper and lower ground speed categories, 3.75 to 10.80 percent. The mode ground speed was associated with above average fines. Two speed categories on either side of the mode ground speed, had lower than the mean
Table 30. Means and F-values for corn damage categorized by ground speed mph for single classification analysis of variance

<table>
<thead>
<tr>
<th>Ground speed less than whole kernel</th>
<th>Percentage broken corn</th>
<th>Percentage fines after simulated handling</th>
</tr>
</thead>
<tbody>
<tr>
<td>in miles per hour</td>
<td>N</td>
<td>Mean</td>
</tr>
<tr>
<td>Less than 1</td>
<td>2</td>
<td>5.25</td>
</tr>
<tr>
<td>1.1-1.5</td>
<td>1</td>
<td>5.82</td>
</tr>
<tr>
<td>1.6-2.0</td>
<td>9</td>
<td>5.71</td>
</tr>
<tr>
<td>2.1-2.5</td>
<td>30</td>
<td>5.01</td>
</tr>
<tr>
<td>2.6-3.0</td>
<td>52</td>
<td>5.04</td>
</tr>
<tr>
<td>3.1-3.5</td>
<td>25</td>
<td>4.91</td>
</tr>
<tr>
<td>3.6-4.0</td>
<td>30</td>
<td>5.82</td>
</tr>
<tr>
<td>4.1-4.5</td>
<td>4</td>
<td>5.86</td>
</tr>
<tr>
<td>Respondents</td>
<td>153</td>
<td>5.24</td>
</tr>
<tr>
<td>Nonrespondents</td>
<td>56</td>
<td>5.05</td>
</tr>
<tr>
<td>Samples</td>
<td>209</td>
<td>5.19</td>
</tr>
</tbody>
</table>

Slightly lower, .20 to .25 percent, levels of damage were observed for nonrespondents compared to the respondent operators.

An analysis of variance test of the data did not provide an F-value adequate to reject \( H_0 \) or \( H_{39} \).

Harvest rates in bushels per hour were categorized for mean kernel damage comparisons.
There were no significant differences in kernel damage means among groups categorized by harvest rates.

There was no significant difference between means for kernel damage for respondents and non-respondents to the harvest rate question.

Table 31 contains information concerning harvest rate and kernel damage. Rates from under 90 to over 560 bushels per hour were indicated. The most frequent harvest rate was 226-360 bushels per hour. Broken corn damage was lowest (4.89) at 161 to 360 bushel rates and (4.75) at the over 561 bushel per hour harvest rate. Percent damage indicated by fines was also lowest (4.48) at the 161-225 bushel per hour, but was higher at the lowest and highest bushels per hour harvest rates.

The F-values produced were such that the null hypotheses were not rejected. Harvest rate in bushels per hour was not significantly associated with kernel damage.

A second measure of combine feed rate, bushel per cylinder inch per 10 hours, was analyzed with kernel damage. The categories, responses, means and F-values are presented in Table 32.

There were no significant difference in mean kernel damage among groups categorized by harvest rate per cylinder inch.

There was no significant difference between means for kernel damage for respondents and non-respondents to the harvest rate and machine make questions.
Table 31. Means and F-values for corn damage categorized by harvest rate for single classification analysis of variance

<table>
<thead>
<tr>
<th>Harvest rate, bushels per hour</th>
<th>Percentage broken corn less than whole kernel</th>
<th>Percentage fines after simulated handling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
</tr>
<tr>
<td>Less than 90</td>
<td>2</td>
<td>7.16</td>
</tr>
<tr>
<td>91-120</td>
<td>10</td>
<td>5.88</td>
</tr>
<tr>
<td>121-160</td>
<td>11</td>
<td>5.35</td>
</tr>
<tr>
<td>161-225</td>
<td>32</td>
<td>4.88</td>
</tr>
<tr>
<td>226-360</td>
<td>51</td>
<td>4.90</td>
</tr>
<tr>
<td>361-400</td>
<td>21</td>
<td>5.68</td>
</tr>
<tr>
<td>401-560</td>
<td>16</td>
<td>5.55</td>
</tr>
<tr>
<td>561 and over</td>
<td>3</td>
<td>4.75</td>
</tr>
<tr>
<td>Respondents</td>
<td>146</td>
<td>5.21</td>
</tr>
<tr>
<td>Nonrespondents</td>
<td>63</td>
<td>5.14</td>
</tr>
<tr>
<td>Samples</td>
<td>209</td>
<td>5.14</td>
</tr>
</tbody>
</table>
Table 32. Means and F-values for corn damage categorized by adjusted harvest rate for single classification analysis of variance

<table>
<thead>
<tr>
<th>Harvest rate bu./cylinder in./10 hrs.</th>
<th>Kernel damage Percentage broken corn less than whole kernel</th>
<th>N</th>
<th>Mean</th>
<th>F</th>
<th>Percentage fines after simulated handling</th>
<th>N</th>
<th>Mean</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 43</td>
<td></td>
<td>12</td>
<td>6.24</td>
<td></td>
<td></td>
<td>11</td>
<td>6.27</td>
<td></td>
</tr>
<tr>
<td>44-63</td>
<td></td>
<td>28</td>
<td>4.80</td>
<td></td>
<td></td>
<td>26</td>
<td>3.91</td>
<td></td>
</tr>
<tr>
<td>64-83</td>
<td></td>
<td>41</td>
<td>4.97</td>
<td></td>
<td></td>
<td>40</td>
<td>4.46</td>
<td></td>
</tr>
<tr>
<td>84-103</td>
<td></td>
<td>34</td>
<td>5.29</td>
<td>1.3195</td>
<td></td>
<td>33</td>
<td>5.20</td>
<td>2.7054*</td>
</tr>
<tr>
<td>104-123</td>
<td></td>
<td>12</td>
<td>4.76</td>
<td></td>
<td></td>
<td>11</td>
<td>5.12</td>
<td></td>
</tr>
<tr>
<td>124 and over</td>
<td></td>
<td>6</td>
<td>5.98</td>
<td></td>
<td></td>
<td>6</td>
<td>6.20</td>
<td></td>
</tr>
<tr>
<td>Respondents</td>
<td></td>
<td>133</td>
<td>5.16</td>
<td></td>
<td></td>
<td>127</td>
<td>4.84</td>
<td></td>
</tr>
<tr>
<td>Nonrespondents</td>
<td></td>
<td>76</td>
<td>5.24</td>
<td>0.0884</td>
<td></td>
<td>75</td>
<td>5.09</td>
<td>0.5266</td>
</tr>
<tr>
<td>Samples</td>
<td></td>
<td>209</td>
<td>5.19</td>
<td>0.0884</td>
<td></td>
<td>202</td>
<td>4.93</td>
<td></td>
</tr>
</tbody>
</table>

*Significant beyond the five percent level.

A threefold variation in harvest rate existed, 43 to over 124 bushels per cylinder inch per 10 hours. With the exception of the lowest harvest rate, damage appeared to increase with harvest rate in bushels per cylinder inch. Low and high rates appeared to result in a higher percentage of damage than the mode rate of 64-83 bushels per cylinder inch. $H_{02}$ was rejected based on an F-value of 2.705 for percentage of fines after handling test analysis.
Harvest rate per cylinder inch per 10 hours was associated with kernel damage after handling simulation. Ho$_{43}$ was not rejected. Respondents and nonrespondents produced near mean damages.

The front concave-cylinder clearances varied from less than five-eighths inch to over 2 5/8 inch. The most frequent spacing was 5/8 to 1 inch. Table 33 contains data concerning mean kernel damage and F-values for front concave clearances.

Ho$_{44}$: There were no significant differences in kernel damage means among groupings by front concave clearance.

Ho$_{45}$: There was no significant difference between means for kernel damage for respondents and non-respondents to the front concave clearance question.

No pattern of relationship of corn damage to concave clearance was apparent. The settings with the most damage in terms of both broken corn and fines were (1) less than 5/8th inch (mean of 5.20) and (2) 1-5/8 to 2 inch clearances (mean of 5.44). Respondents (5.04) and nonrespondents (5.10) were near the overall mean of 5.06. The F-values at the five percent level did not justify rejection of the hypotheses.

Rear cylinder-concave clearance groupings are found in Table 34. Five clearance categories were established. The most frequent clearance was 5/8 to 1 inch.
Table 33. Means and F-values for corn damage categorized by front concave clearance for single classification analysis of variance

<table>
<thead>
<tr>
<th>Front concave clearance, inches</th>
<th>Kernel damage</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Percentage broken corn less than whole kernel</td>
<td>Percentage fines after simulated handling</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
<td>F</td>
<td>N</td>
</tr>
<tr>
<td>Less than 5/8</td>
<td>21</td>
<td>5.11</td>
<td>18</td>
<td>5.29</td>
</tr>
<tr>
<td>5/8 - 1</td>
<td>66</td>
<td>5.25</td>
<td>64</td>
<td>4.71</td>
</tr>
<tr>
<td>1-1/8 - 1-1/2</td>
<td>40</td>
<td>4.79</td>
<td>39</td>
<td>5.24</td>
</tr>
<tr>
<td>1-5/8 - 2</td>
<td>6</td>
<td>5.28</td>
<td>0.3913</td>
<td>6</td>
</tr>
<tr>
<td>2-1/8 - 2-1/2</td>
<td>1</td>
<td>4.75</td>
<td>1</td>
<td>3.60</td>
</tr>
<tr>
<td>2-5/8 and greater</td>
<td>1</td>
<td>6.44</td>
<td>1</td>
<td>4.40</td>
</tr>
<tr>
<td>Respondents</td>
<td>135</td>
<td>5.10</td>
<td>129</td>
<td>4.98</td>
</tr>
<tr>
<td>Nonrespondents</td>
<td>74</td>
<td>5.35</td>
<td>0.8631</td>
<td>73</td>
</tr>
<tr>
<td>Samples</td>
<td>209</td>
<td>5.19</td>
<td>202</td>
<td>4.93</td>
</tr>
</tbody>
</table>
Table 34. Means and F-values for corn damage categorized by rear concave clearance for single classification analysis of variance

<table>
<thead>
<tr>
<th>Rear concave clearance (inches)</th>
<th>Kernel damage</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Percentage broken corn less than whole kernel</td>
<td>Percentage fines after simulated handling</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
<td>F</td>
</tr>
<tr>
<td>1/8 - 1/2</td>
<td>34</td>
<td>5.39</td>
<td></td>
</tr>
<tr>
<td>5/8 - 1</td>
<td>67</td>
<td>4.74</td>
<td></td>
</tr>
<tr>
<td>1-1/8 - 1-1/2</td>
<td>9</td>
<td>5.97</td>
<td>1.5679</td>
</tr>
<tr>
<td>1-5/8 - 2</td>
<td>6</td>
<td>4.57</td>
<td></td>
</tr>
<tr>
<td>2-1/8 and greater</td>
<td>2</td>
<td>3.89</td>
<td></td>
</tr>
<tr>
<td>Respondents</td>
<td>118</td>
<td>5.00</td>
<td></td>
</tr>
<tr>
<td>Nonrespondents</td>
<td>91</td>
<td>5.43</td>
<td>2.6839</td>
</tr>
<tr>
<td>Samples</td>
<td>209</td>
<td>5.19</td>
<td></td>
</tr>
</tbody>
</table>

H₀₄₆: There were no significant differences in kernel damage means among groups categorized by rear concave clearance.

H₀₄₇: There was no significant difference between kernel damage means for respondents and non-respondents to the rear concave clearance question.

Kernel damage percentages were high, 5.39 broken corn and 5.63 fines, for the 1/8 to 1/2 inch rear concave setting. The least damage was found for two samples associated with over two inch rear concave clearances. No trend in moderate settings was evidenced. The respondent
versus nonrespondent comparison indicated minor variation from the means for broken corn and for fines. The F-values (.009 to 1.568) produced by analysis of variance did not permit the rejection of the null hypotheses.

Cylinder speed in revolutions per minute was categorized into four groups. The percentage of kernel damage and F-values produced are presented in Table 35.

$H_{o48}$: There were no significant differences in kernel damage among groups categorized by differing cylinder speed.

$H_{o49}$: There was no significant difference in mean kernel damage for respondents and nonrespondents to the cylinder speed question.

The percentage of broken corn increased with cylinder speed. The lowest, 370-519 rpm, group had 4.98 percentage of damage compared to 8.30 percentage of broken corn for the 820-999 rpm group. A significant F of 3.69 permitted the rejection of $H_{o48}$.

Significant difference existed in corn damage when samples were categorized by cylinder speed. $H_{o49}$ was not rejected. Respondent and nonrespondent data were basically alike.

Cylinders varied in diameter from 15-1/4 inches for the International 205 to the more common 22 inch cylinders. Table 36 contains data for categorization of cylinder speed adjusted to equate peripheral speed per revolution per minute.
Table 35. Means and F-values for corn damage categorized by cylinder speed for single classification analysis of variance

<table>
<thead>
<tr>
<th>Cylinder speed in rev. per minute</th>
<th>Kernel damage</th>
<th>Percentage broken corn less than whole kernel</th>
<th>Percentage fines after simulated handling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
<td>F</td>
</tr>
<tr>
<td>370-519</td>
<td>64</td>
<td>4.98</td>
<td></td>
</tr>
<tr>
<td>520-669</td>
<td>66</td>
<td>5.11</td>
<td></td>
</tr>
<tr>
<td>670-819</td>
<td>8</td>
<td>6.20</td>
<td>3.6989*</td>
</tr>
<tr>
<td>820-999</td>
<td>3</td>
<td>8.30</td>
<td></td>
</tr>
<tr>
<td>Respondents</td>
<td>141</td>
<td>5.18</td>
<td></td>
</tr>
<tr>
<td>Nonrespondents</td>
<td>68</td>
<td>5.20</td>
<td>0.0058</td>
</tr>
<tr>
<td>Samples</td>
<td>209</td>
<td>5.19</td>
<td></td>
</tr>
</tbody>
</table>

* Significant beyond the five percent level.

H_{o50}: There were no significant differences in means for kernel damage among samples categorized by adjusted cylinder speed.

H_{o51}: There was no significant difference in means for kernel damage of respondents and non-respondents to the cylinder speed and machine make questions.
Table 36. Means and F-values for corn damage categorized by adjusted cylinder speed for single classification analysis of variance

<table>
<thead>
<tr>
<th>Adjusted cylinder speed in rev. per minute</th>
<th>Kernel damage</th>
<th></th>
<th>Percentage fines after simulated handling</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>310-409</td>
<td>N</td>
<td>Mean</td>
<td>F</td>
<td>N</td>
</tr>
<tr>
<td>13</td>
<td>5.39</td>
<td>12</td>
<td>3.97</td>
<td></td>
</tr>
<tr>
<td>410-509</td>
<td>60</td>
<td>4.86</td>
<td>58</td>
<td>5.00</td>
</tr>
<tr>
<td>510-609</td>
<td>54</td>
<td>5.10</td>
<td>51</td>
<td>5.12</td>
</tr>
<tr>
<td>610-709</td>
<td>10</td>
<td>6.40</td>
<td>10</td>
<td>5.81</td>
</tr>
<tr>
<td>710-999</td>
<td>4</td>
<td>7.41</td>
<td>4</td>
<td>4.22</td>
</tr>
<tr>
<td>Respondents</td>
<td>141</td>
<td>5.18</td>
<td>135</td>
<td>4.99</td>
</tr>
<tr>
<td>Nonrespondents</td>
<td>68</td>
<td>5.20</td>
<td>67</td>
<td>4.81</td>
</tr>
<tr>
<td>Samples</td>
<td>209</td>
<td>5.19</td>
<td>202</td>
<td>4.93</td>
</tr>
</tbody>
</table>

*Significant beyond the five percent level.

Kernel damage percentages, for both broken corn and fines damage measures, indicated a general increase in damage occurred with increased cylinder peripheral speed. Respondents and nonrespondents had damage levels similar to the overall mean of 5.19 percent broken corn and 4.93 percent fines. A significant F of 2.858 provided for rejection of $H_{0.50}$. $H_{0.51}$ was not rejected. Kernel damage as broken corn was greater at higher adjusted cylinder speeds than at more moderate speeds.

A summary of the analysis of variance findings provide
the test information for $H_0^1$ and $H_0^2$. $H_0^1$ was rejected. Significant differences in kernel damage, tested by analysis of variance F-value levels, were obtained for the following data categorizations: (1) kernel damage measured as fines with data grouped by moisture content (Table 12), (2) kernel damage measured as fines by test weight per bushel (Table 13), (3) kernel damage measured as broken corn by crop standability (Table 15), (4) kernel damage as fines with data categorized by harvest rate in bushels per cylinder inch per 10 hours (Table 32), (5) kernel damage as broken corn, data categorized according to cylinder speed (Table 35), and (6) kernel damage as broken corn with information grouped by adjusted cylinder speed (Table 36).

$H_0^2$ was rejected. A statistically significant difference in damaged kernel percentages was observed and tested between respondents and nonrespondents to the vo-ag class items on the questionnaire (Tables 24 and 25).

Multivariable Kernel Damage Relationships

The relationship of harvest variables in combinations to kernel damage was analyzed by stepwise regression. The stepwise regression model by which the data were analyzed is specified in the method of procedure chapter.

The independent harvest variables listed in Tables 1, 2, 3, and 5 were applied as predictor variables in the
stepwise regression process.

Percentage of broken corn of less than whole kernel size, percentage of sound kernels, and percentage of fines resulting from simulated handling, were the three damage measures treated as dependent variables for stepwise regression. Regression computations were completed for the above three dependent variables.

The predictor variables, their partial regression coefficients and $R$-square change effect, and the $F$-values for the regression coefficients resulting from stepwise regression on the damage measure, percentage broken corn, less than whole kernel, are presented in Table 37.

The harvesting variables that were the major contributors toward the multiple correlation of the prediction equation with kernel damage were: (1) combine make (.070), (2) corn variety (.069), (3) feed rate in bushels per cylinder inch (.054), (4) cylinder speed (.042), and (5) corn test weight (.032).

The prediction equation resulting from stepwise regression of broken corn on corn harvest variables was as follows:

$$\hat{Y}_{bc1} = 3.948 + 1.259X_4 + 1.166X_2 + 0.015X_{13} + 0.004X_7$$
$$- 0.375X_{26} + 0.105X_{16} + 0.585X_{22} + 0.287X_{18} - 0.004X_{12}$$
$$+ 0.001X_{21} + 0.693X_9 - 0.294X_{10} - 0.203X_{25} - 0.020X_{20}$$
\[ + 0.011X_3 + 0.956X_{19} + 0.220X_{24} - 0.076X_{17} - 0.002X_1 \]

\[ -0.100X_{15}. \]

Table 37. Regression coefficients of variables selected by stepwise regression for predicting percentage of broken corn less than whole kernel size

<table>
<thead>
<tr>
<th>Variables</th>
<th>B</th>
<th>Std. error</th>
<th>( R^2 ) change</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>( X_4 ) Combine make</td>
<td>1.259</td>
<td>0.433</td>
<td>.070</td>
<td>8.460**</td>
</tr>
<tr>
<td>( X_2 ) Corn variety</td>
<td>1.166</td>
<td>0.496</td>
<td>.069</td>
<td>5.534**</td>
</tr>
<tr>
<td>( X_{13} ) Bu/cyl. in/10 hrs</td>
<td>0.015</td>
<td>0.005</td>
<td>.054</td>
<td>8.727**</td>
</tr>
<tr>
<td>( X_7 ) Cylinder rpm</td>
<td>0.004</td>
<td>0.002</td>
<td>.042</td>
<td>4.102**</td>
</tr>
<tr>
<td>( X_{26} ) Corn test weight</td>
<td>-0.375</td>
<td>0.200</td>
<td>.032</td>
<td>3.507**</td>
</tr>
<tr>
<td>( X_{16} ) Highest grade educ.</td>
<td>0.105</td>
<td>0.119</td>
<td>.016</td>
<td>0.766</td>
</tr>
<tr>
<td>( X_{22} ) Knowledge source</td>
<td>0.585</td>
<td>0.553</td>
<td>.014</td>
<td>1.121</td>
</tr>
<tr>
<td>( X_{18} ) Post high school vo-ag</td>
<td>0.287</td>
<td>0.356</td>
<td>.011</td>
<td>0.647</td>
</tr>
<tr>
<td>( X_{12} ) Bushel/hour</td>
<td>-0.004</td>
<td>0.002</td>
<td>.008</td>
<td>2.395**</td>
</tr>
<tr>
<td>( X_{21} ) Combine expr. A s.</td>
<td>0.001</td>
<td>0.001</td>
<td>.011</td>
<td>0.662</td>
</tr>
<tr>
<td>( X_9 ) Concave clear. f.</td>
<td>0.693</td>
<td>0.510</td>
<td>.009</td>
<td>1.845*</td>
</tr>
<tr>
<td>( X_{10} ) Concave clear. r.</td>
<td>-0.294</td>
<td>0.482</td>
<td>.008</td>
<td>0.372</td>
</tr>
<tr>
<td>( X_{25} ) Moisture content</td>
<td>-0.203</td>
<td>0.188</td>
<td>.007</td>
<td>1.168</td>
</tr>
<tr>
<td>( X_{20} ) Combine expr. yr.</td>
<td>-0.020</td>
<td>0.026</td>
<td>.006</td>
<td>0.563</td>
</tr>
<tr>
<td>( X_3 ) Yield per acre</td>
<td>0.011</td>
<td>0.014</td>
<td>.004</td>
<td>0.548</td>
</tr>
</tbody>
</table>

\* .01 level of significance, 2.20 at 20, 61 degrees of freedom.

\* .05 level of significance, 1.75 at 20, 61 degrees of freedom.
Table 37 (Continued)

<table>
<thead>
<tr>
<th>Variables</th>
<th>B</th>
<th>Std. error</th>
<th>$R^2$ change</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X_{19}$ Operator status</td>
<td>0.956</td>
<td>1.773</td>
<td>0.003</td>
<td>0.291</td>
</tr>
<tr>
<td>$X_{24}$ Mech. rating</td>
<td>0.220</td>
<td>0.441</td>
<td>0.002</td>
<td>0.248</td>
</tr>
<tr>
<td>$X_{17}$ Year vo-ag. h.s.</td>
<td>-0.076</td>
<td>0.142</td>
<td>0.002</td>
<td>0.286</td>
</tr>
<tr>
<td>$X_{1}$ Harvest date</td>
<td>-0.002</td>
<td>0.004</td>
<td>0.001</td>
<td>0.246</td>
</tr>
<tr>
<td>$X_{15}$ Age of operator</td>
<td>-0.100</td>
<td>0.204</td>
<td>0.002</td>
<td>0.240</td>
</tr>
<tr>
<td>C Constant</td>
<td>3.948</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The predicted percentage of broken corn kernel damage was $\hat{Y}_{bcl}$. The independent $X$ variables are identified in Table 37. The prediction equation as presented was tested for significance.

$H_0_{52}$: The slope of the broken corn regression line was zero.

The data for the testing of the regression equation are provided in Table 38. An $F$-value of 1.800 was significant at the .05 level and the null hypothesis, $H_0_{52}$, was rejected. The equation for predicting percentage broken corn accounted for 37.1 percent of the variation in kernel damage observed among the corn samples.

The predictor variables selected by the stepwise regression process, and the associated data, for the regression of percentage of sound kernels on the harvesting variables are provided in Table 39.
Table 38. Analysis of stepwise regression of broken corn less than whole kernel size on corn harvest variables

<table>
<thead>
<tr>
<th>Source</th>
<th>d.f.</th>
<th>Mean square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>20</td>
<td>5.444</td>
<td>1.800*</td>
</tr>
<tr>
<td>Residual</td>
<td>61</td>
<td>3.025</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>81</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[ R^2 = 0.371 \quad \text{Standard Error} = 1.739 \]

*.05 level of significance, 1.75 at 20, 61 degrees of freedom.

Table 39. Regression coefficients of variables selected by stepwise regression for predicting percentage of sound kernels

<table>
<thead>
<tr>
<th>Variable</th>
<th>B</th>
<th>Std. Error</th>
<th>( R^2 ) change</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>( X_{20} ) Combine expr. yrs.</td>
<td>.319</td>
<td>0.198</td>
<td>.051</td>
<td>2.594**</td>
</tr>
<tr>
<td>( X_4 ) Combine make</td>
<td>-7.403</td>
<td>3.100</td>
<td>.042</td>
<td>5.703**</td>
</tr>
<tr>
<td>( X_{10} ) Concave clear. r.</td>
<td>-7.136</td>
<td>3.148</td>
<td>.043</td>
<td>5.138**</td>
</tr>
<tr>
<td>( X_{23} ) Freq. adjustment</td>
<td>-2.180</td>
<td>1.370</td>
<td>.040</td>
<td>2.534**</td>
</tr>
<tr>
<td>( X_5 ) Header, rows</td>
<td>2.269</td>
<td>1.693</td>
<td>.013</td>
<td>1.797</td>
</tr>
<tr>
<td>( X_{13} ) Bu./cyl. in/10 hrs.</td>
<td>-0.053</td>
<td>0.033</td>
<td>.024</td>
<td>2.633**</td>
</tr>
<tr>
<td>( X_{15} ) Age of operator</td>
<td>1.715</td>
<td>1.458</td>
<td>.008</td>
<td>1.383</td>
</tr>
<tr>
<td>( X_{26} ) Corn test weight</td>
<td>0.963</td>
<td>0.999</td>
<td>.005</td>
<td>0.929</td>
</tr>
<tr>
<td>( X_{24} ) Mech. rating</td>
<td>-3.422</td>
<td>3.399</td>
<td>.005</td>
<td>1.014</td>
</tr>
</tbody>
</table>

**.01 level of significance, 2.45 at 12, 69 degrees of freedom.
The harvesting variables that displayed the strongest association, as indicated by R-square change, with percentage of sound kernels were: (1) operator combining experience in years (.051), (2) combine make (.042), (3) rear concave clearance (.043), and (4) frequency of machine adjustment per day (.040). Operator experience exhibited a positive relationship with percentage of sound kernels. Combine make was identified by the mean kernel damage observed in corn samples processed by that machine make, and did logically display a negative relationship with the percentage of sound kernels. Rear concave clearance was negatively associated with percentage of sound kernels. The regression coefficient of -2.18 for frequency of machine adjustment indicated that fewer machine adjustments per day resulted in more sound kernels.

The equation for predicting the percentage of sound kernels formulated by stepwise regression on harvest variables
was:
\[ \hat{Y}_{s1} = 68.008 + 0.319X_{20} - 7.403X_{4} - 7.136X_{10} - 2.180X_{23} \]
\[ + 2.269X_{5} - 0.053X_{13} + 1.715X_{15} + 0.963X_{26} \]
\[ - 3.422X_{24} - 4.081X_{2} - 2.781X_{14} - 0.423X_{6}. \]
The predicted percentage of sound kernels was expressed in \( \hat{Y}_{s1} \). The X variables are listed in Table 39. The F-value for each partial regression coefficient in the prediction equation is given in Table 39. The F-value was an indication of the significance that was attributable to the partial regression coefficient value in the regression equation.

The equation for predicting the percentage of sound kernels in harvested shelled corn was tested for significance by analysis of variance.

\( H_{053} \): The slope of the sound kernel regression line was equal to zero.

The data required to test \( H_{053} \) are presented in Table 40. An F-value of 1.950 significant at the .05 level, was sufficient to reject the null hypothesis. The prediction equation had predictive value. The R-square (.253) and the standard error of prediction (13.828), from Table 40, indicated much of the variation in percentage of sound kernels in harvested shelled corn was not explained by the prediction equation.
### Table 40. Analysis of stepwise regression of sound kernels on corn harvest variables

<table>
<thead>
<tr>
<th>Source</th>
<th>d.f.</th>
<th>Mean Square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>12</td>
<td>373.3</td>
<td>1.950*</td>
</tr>
<tr>
<td>Residual</td>
<td>69</td>
<td>191.2</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>81</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$R^2 = 0.253$  Standard error 13.828

* .05 level of significance, 1.89 at 12, 69 degrees of freedom.

A prediction equation to establish the relationship of the corn harvesting variables, recorded in Tables 1, 2, 3 and 5, to kernel damage during harvest, as measured by the percentage of fines after simulated handling, was developed by stepwise regression. The predictor variables, in the order of their inclusion in the regression equation, appear in Table 41.

The influence of a predictor variable on the accuracy of the regression equation is indicated by the R-square value. The predictor variables that were most effective in contributing to the prediction of percentage of fines after simulated handling treatment, and the R-square change for each were: (1) test weight (.0162), (2) harvest rate in bushels per cylinder inch (.020), (3) combine make (.018), (4) header
Table 41. Regression coefficients of variables selected by stepwise regression for predicting percentage of fines following simulated handling test

<table>
<thead>
<tr>
<th>Variable</th>
<th>B</th>
<th>Std. error</th>
<th>$R^2$ change</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X_{26}$ Test weight</td>
<td>-0.423</td>
<td>0.162</td>
<td>0.097</td>
<td>6.823**</td>
</tr>
<tr>
<td>$X_{13}$ Bu./cyl. in./10 hrs.</td>
<td>0.009</td>
<td>0.005</td>
<td>0.020</td>
<td>2.782**</td>
</tr>
<tr>
<td>$X_4$ Combine make</td>
<td>1.083</td>
<td>0.555</td>
<td>0.018</td>
<td>3.801**</td>
</tr>
<tr>
<td>$X_5$ Header size, rows</td>
<td>-0.431</td>
<td>0.282</td>
<td>0.014</td>
<td>2.331*</td>
</tr>
<tr>
<td>$X_7$ Harvest date</td>
<td>-0.006</td>
<td>0.004</td>
<td>0.018</td>
<td>1.734</td>
</tr>
<tr>
<td>$X_9$ Concave clear. f.</td>
<td>0.493</td>
<td>0.582</td>
<td>0.007</td>
<td>0.717</td>
</tr>
<tr>
<td>$X_{17}$ Years vo-ag, h.s.</td>
<td>-0.147</td>
<td>0.162</td>
<td>0.006</td>
<td>0.825</td>
</tr>
<tr>
<td>$X_{19}$ Operator, status</td>
<td>1.872</td>
<td>2.190</td>
<td>0.008</td>
<td>0.731</td>
</tr>
<tr>
<td>C Constant</td>
<td>14.228</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

** .01 level of significance, 2.77 at 8, 73 degrees of freedom.
* .05 level of significance, 2.07 at 8, 73 degrees of freedom.

size (.014), and (5) harvest date (.018). Corn test weight had a negative relationship with percentage of fines. Harvest rate and combine make had a positive relationship with percentage of fines. Percentage of fines tended to decrease as header size increased, and when harvest date was delayed.

The equation resulting from stepwise regression for the prediction of percentage of fines observed following the
simulated handling treatment was: 

\[ \hat{Y}_{f1} = 14.228 - 0.423X_{26} + 0.009X_{13} + 1.083X_{4} - 0.431X_{5} - 0.006X_{1} + 0.493X_{9} - 0.147X_{17} + 1.872X_{19}. \]

\( H_{0_{54}}: \) The slope of the regression line for percentage of fines was equal to zero.

The data to test \( H_{0_{54}} \) are provided in Table 42. An F-value of 2.121 was significant at the .05 level with 8 and 73 degrees of freedom. The null hypothesis was rejected. The R-square value (.189) from the regression equation indicated about one-fifth of the variation in the percentage of fines following simulated handling was accounted for by the prediction equation. The standard error for prediction was 2.3 percentage points.

Table 42. Analysis of stepwise regression of simulated handling test fines on corn harvest variables

<table>
<thead>
<tr>
<th>Source</th>
<th>d.f.</th>
<th>Mean square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>8</td>
<td>11.221</td>
<td>2.121*</td>
</tr>
<tr>
<td>Residual</td>
<td>73</td>
<td>5.291</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>81</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\( R^2 = 0.189 \) Standard error = 2.300

* .05 level of significance, 2.07 at 8, 73 degrees of freedom.
Harvest Damage Measures Regressed on Factor Variables

The data were treated to identify harvest variable commonalities and to reduce inter-variable correlation via factor analysis of the independent variables. The variables data were treated by a computerized program for rotated orthogonal factor analysis described by Nie et al. (32). Nine unique factors were identified. The factor loadings of each harvest variable treated are presented in Table 43.

The harvest variables that loaded heavily on factor 1 were: (1) harvest rate in bushels per hour (.97), (2) header size in rows (.72), (3) harvest rate in bushels per cylinder inch (.79) and (4) yield per acre (.68).

The harvest variables that loaded heavily on factor 2 were: (1) cylinder speed in revolutions per minute (.90), and (2) cylinder speed adjusted to equate cylinder diameter variations (.88).

The major harvest variable loadings on factor 3 were: (1) crop standability (.73), (2) corn variety (-.65), (3) operator experience in years (.51), and (4) row spacing (-.48).

The harvest variables with the larger loadings on factor 4 were: (1) row space (.60), and (2) machine make (-.57).

The harvest variables loading heavily on factor 5 were: (1) test weight per bushel (-.91), and (2) corn moisture
Table 43. Loadings, regression coefficients, of rotated orthogonal factors on selected independent variables

<table>
<thead>
<tr>
<th>Independent variables</th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
<th>F4</th>
<th>F5</th>
<th>F6</th>
<th>F7</th>
<th>F8</th>
<th>F9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield per acre</td>
<td>.68</td>
<td>-.06</td>
<td>-.05</td>
<td>.06</td>
<td>.03</td>
<td>.26</td>
<td>-.21</td>
<td>-.02</td>
<td>-.12</td>
</tr>
<tr>
<td>Header rows</td>
<td>.72</td>
<td>-.14</td>
<td>.09</td>
<td>.12</td>
<td>-.06</td>
<td>-.04</td>
<td>.06</td>
<td>.08</td>
<td></td>
</tr>
<tr>
<td>Row space, in.</td>
<td>-.27</td>
<td>-.22</td>
<td>-.48</td>
<td>-.60</td>
<td>.10</td>
<td>-.23</td>
<td>-.03</td>
<td>-.02</td>
<td>-.02</td>
</tr>
<tr>
<td>Cyl. speed</td>
<td>-.21</td>
<td>.90</td>
<td>.01</td>
<td>-.10</td>
<td>-.01</td>
<td>-.03</td>
<td>-.01</td>
<td>.09</td>
<td>-.09</td>
</tr>
<tr>
<td>Cyl. speed adj.</td>
<td>-.13</td>
<td>.88</td>
<td>-.08</td>
<td>.22</td>
<td>.12</td>
<td>-.10</td>
<td>.01</td>
<td>.09</td>
<td>.02</td>
</tr>
<tr>
<td>Concave clear.f.</td>
<td>.22</td>
<td>.33</td>
<td>-.22</td>
<td>.41</td>
<td>.10</td>
<td>-.25</td>
<td>.11</td>
<td>.69</td>
<td>.10</td>
</tr>
<tr>
<td>Concave clear.r.</td>
<td>-.21</td>
<td>.08</td>
<td>.01</td>
<td>-.08</td>
<td>-.04</td>
<td>.05</td>
<td>-.09</td>
<td>.70</td>
<td>.11</td>
</tr>
<tr>
<td>Ground speed, mph</td>
<td>-.22</td>
<td>.08</td>
<td>-.06</td>
<td>-.10</td>
<td>.05</td>
<td>-.08</td>
<td>-.02</td>
<td>-.14</td>
<td>-.86</td>
</tr>
<tr>
<td>Harvest rate, bu/hr</td>
<td>.97</td>
<td>-.09</td>
<td>-.03</td>
<td>-.04</td>
<td>.09</td>
<td>.08</td>
<td>.09</td>
<td>-.10</td>
<td>.09</td>
</tr>
<tr>
<td>Harvest rate, adj.</td>
<td>.79</td>
<td>-.00</td>
<td>.05</td>
<td>.04</td>
<td>.07</td>
<td>.11</td>
<td>.08</td>
<td>-.20</td>
<td>.10</td>
</tr>
<tr>
<td>Standability, crop</td>
<td>.07</td>
<td>-.10</td>
<td>.73</td>
<td>.27</td>
<td>.19</td>
<td>-.19</td>
<td>-.03</td>
<td>.07</td>
<td>.04</td>
</tr>
<tr>
<td>Operator age</td>
<td>-.03</td>
<td>.29</td>
<td>.17</td>
<td>.32</td>
<td>.31</td>
<td>-.63</td>
<td>-.16</td>
<td>.11</td>
<td>-.07</td>
</tr>
<tr>
<td>Educ. general</td>
<td>.13</td>
<td>.04</td>
<td>-.08</td>
<td>.10</td>
<td>.11</td>
<td>.41</td>
<td>.19</td>
<td>-.27</td>
<td>.21</td>
</tr>
<tr>
<td>Years h.s. vo-ag</td>
<td>.11</td>
<td>-.05</td>
<td>.02</td>
<td>-.03</td>
<td>.33</td>
<td>.54</td>
<td>.09</td>
<td>.09</td>
<td>-.07</td>
</tr>
<tr>
<td>Post h.s. vo-ag</td>
<td>-.40</td>
<td>-.35</td>
<td>-.04</td>
<td>.22</td>
<td>-.18</td>
<td>.13</td>
<td>.02</td>
<td>-.03</td>
<td>-.10</td>
</tr>
<tr>
<td>Years experience</td>
<td>.28</td>
<td>.18</td>
<td>.51</td>
<td>-.01</td>
<td>-.01</td>
<td>-.21</td>
<td>.34</td>
<td>.17</td>
<td>-.12</td>
</tr>
<tr>
<td>Acres experience</td>
<td>.56</td>
<td>-.14</td>
<td>.26</td>
<td>-.29</td>
<td>.00</td>
<td>-.15</td>
<td>-.01</td>
<td>.05</td>
<td>.02</td>
</tr>
<tr>
<td>Freq. mach. adj.</td>
<td>-.08</td>
<td>-.19</td>
<td>.20</td>
<td>-.09</td>
<td>.09</td>
<td>.29</td>
<td>.23</td>
<td>.25</td>
<td>.10</td>
</tr>
<tr>
<td>Mech. rating</td>
<td>.42</td>
<td>.11</td>
<td>.30</td>
<td>-.38</td>
<td>-.20</td>
<td>.30</td>
<td>.15</td>
<td>.14</td>
<td>.03</td>
</tr>
<tr>
<td>Moisture, %</td>
<td>.30</td>
<td>.02</td>
<td>-.07</td>
<td>.16</td>
<td>.76</td>
<td>.19</td>
<td>-.01</td>
<td>.01</td>
<td>.12</td>
</tr>
<tr>
<td>Test weight</td>
<td>-.01</td>
<td>-.12</td>
<td>-.08</td>
<td>.14</td>
<td>-.91</td>
<td>.01</td>
<td>-.08</td>
<td>.03</td>
<td>.10</td>
</tr>
<tr>
<td>Variety</td>
<td>.01</td>
<td>.05</td>
<td>-.65</td>
<td>.14</td>
<td>.07</td>
<td>-.08</td>
<td>.04</td>
<td>.04</td>
<td>-.03</td>
</tr>
<tr>
<td>Machine make</td>
<td>.06</td>
<td>.01</td>
<td>.01</td>
<td>-.57</td>
<td>.01</td>
<td>.10</td>
<td>-.01</td>
<td>.01</td>
<td>-.09</td>
</tr>
<tr>
<td>Farming status,</td>
<td>-.16</td>
<td>.04</td>
<td>-.04</td>
<td>.07</td>
<td>.12</td>
<td>.27</td>
<td>.90</td>
<td>-.00</td>
<td>.07</td>
</tr>
<tr>
<td>operator</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Source of knowledge</td>
<td>-.35</td>
<td>.26</td>
<td>-.13</td>
<td>.18</td>
<td>.18</td>
<td>-.09</td>
<td>-.50</td>
<td>.17</td>
<td>.41</td>
</tr>
</tbody>
</table>

Education related harvest variables loaded most heavily on factor 6 were as follows: (1) operator age (-.63), (2) years vo-ag in high school (.54), and (3) years of general
education (.41).

Factor 7 was heavily loaded by (1) farming status of the operator (.90), and (2) source of operating knowledge (-.50).

Concave clearances were the variables loading heavily on factor 8 as follows: (1) rear concave clearance (.70), and (2) front concave clearance (.69). Factor 9 was loaded heavily by one variable, ground speed of the machine (-.86).

The nine factors identified by factor analysis and described in terms of harvest variable loadings comprised a reduced set of derived harvest variables. The variables derived from factor analysis of the independent harvest variables termed factor variables are defined in terms of the original variable data as follows: (1) factor 1 was equal to harvest rate in bushels per hour; (2) factor 2 was equal to cylinder speed in revolutions per minute plus adjusted cylinder speed in revolutions per minute (adjusted cylinder speed was equal to cylinder diameter in inches divided by 22 multiplied by the cylinder revolutions per minute); (3) factor 3 was corn standability plus operator years of combining experience minus the variety mean percentage of broken corn; (4) factor 4 was row spacing in inches plus the combine make mean percentage broken corn; (5) factor 5 was minus five times the corn test weight plus three times corn moisture content; (6) factor 6 was minus six times the operator age category plus four times
the operator years of schooling plus five times the quantity, operator years of high school vo-ag plus one; (7) factor 7 was two times mean percentage broken corn of the operator status category minus one time the mean percentage broken corn of the operator's source of knowledge category; (8) factor 8 was front concave to cylinder clearance in inches plus rear concave to cylinder clearance in inches; and (9) factor 9 was harvest machine ground speed in miles per hour.

The three dependent variables previously regressed on the harvest variables and four dependent variables (listed in Table 4) not previously regressed on harvest variables namely: (1) BCFM, ISU, (2) broken corn over 12/64th inch and less than whole kernel size, (3) whole kernels with damaged pericarp, and (4) germination, were regressed on the factor derived harvest variables.

The results of stepwise regression of the seven measures of kernel damage regressed on the nine factor-derived harvest variables are arrayed in Tables 44 through 57.

The factor variables (factor-derived harvest variables) in the order selected, the regression coefficients, and the R-square change resulting from stepwise regression computations are displayed in Table 44. The independent variables that would have the greatest effect in the prediction of corn fines (BCFM, ISU) as indicated by R-square were: (1) factor 3 (.039), (2) factor 7 (.033), (3) factor 4 (.016),
### Table 44. Regression coefficients of factor derived harvest variables for predicting percent corn fines

<table>
<thead>
<tr>
<th>Variables</th>
<th>B</th>
<th>Std. error</th>
<th>$R^2$ change</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X_{103}$</td>
<td>Factor 3</td>
<td>0.0120</td>
<td>0.007</td>
<td>0.039</td>
</tr>
<tr>
<td>$X_{107}$</td>
<td>Factor 7</td>
<td>-0.1620</td>
<td>0.125</td>
<td>0.033</td>
</tr>
<tr>
<td>$X_{104}$</td>
<td>Factor 4</td>
<td>0.0155</td>
<td>0.015</td>
<td>0.016</td>
</tr>
<tr>
<td>$X_{101}$</td>
<td>Factor 1</td>
<td>0.0005</td>
<td>0.000</td>
<td>0.020</td>
</tr>
<tr>
<td>$X_{105}$</td>
<td>Factor 5</td>
<td>-0.0029</td>
<td>0.004</td>
<td>0.013</td>
</tr>
<tr>
<td>$X_{109}$</td>
<td>Factor 9</td>
<td>-0.0283</td>
<td>0.057</td>
<td>0.010</td>
</tr>
<tr>
<td>$X_{108}$</td>
<td>Factor 8</td>
<td>0.0265</td>
<td>0.065</td>
<td>0.003</td>
</tr>
<tr>
<td>$X_{102}$</td>
<td>Factor 2</td>
<td>-0.0001</td>
<td>0.000</td>
<td>0.003</td>
</tr>
<tr>
<td>$X_{106}$</td>
<td>Factor 6</td>
<td>-0.0004</td>
<td>0.003</td>
<td>0.000</td>
</tr>
<tr>
<td>C</td>
<td>Constant</td>
<td>-0.0153</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* .05 level of significance, 2.12 at 9, 40 degrees of freedom.

and (4) factor 1 (.020).

The prediction equation formulated by stepwise regression was:

$$
\hat{Y}_{f2} = -0.0153 + 0.0120X_{103} - 0.162X_{107} + 0.0155X_{104} \\
+ 0.0005X_{101} - 0.0029X_{105} - 0.0283X_{109} + 0.0265X_{108} \\
- 0.0001X_{102} - 0.0004X_{106} .
$$

Predicted percentage of corn fines is symbolized $\hat{Y}_{f2}$, X variables are listed in Table 44.
Ho$_{55}$: The slope of the percentage of fines regression line was equal to zero.

The statistics resulting from analysis of variance of regression are presented in Table 45. A nonsignificant F-value of 0.705 was insufficient to reject the null hypothesis. No significant relationship between the nine factors and percentage of fines was observed.

The relationship of factor variables to percentage of cracked, chipped and broken corn over 12/64th inch, but less than whole kernel size, was also investigated. The factors, in order of inclusion, and the coefficients of partial correlation developed via stepwise regression of the sample data are provided in Table 46. The factor variables exhibiting the stronger relationships to broken corn over 12/64th inch as indicated by R-square values were: (1) factor 1 (.070), (2) factor 2 (.094), (3) factor 4 (.038) and (4) factor 6 (.045).

Table 45. Stepwise regression of corn fines on factor derived harvest variables

<table>
<thead>
<tr>
<th>Source</th>
<th>d.f.</th>
<th>Mean square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>9</td>
<td>0.081</td>
<td>0.705</td>
</tr>
<tr>
<td>Residual</td>
<td>40</td>
<td>0.115</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R^2 = 0.137$</td>
<td></td>
<td>Standard error = 0.339</td>
<td></td>
</tr>
</tbody>
</table>
Table 46. Regression coefficients of factor derived harvest variables for predicting percent cracked, chipped and less than whole kernels

<table>
<thead>
<tr>
<th>Variables</th>
<th>B</th>
<th>Std. error</th>
<th>$R^2$ change</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X_{101}$ Factor 1</td>
<td>0.004</td>
<td>0.002</td>
<td>.070</td>
<td>6.118**</td>
</tr>
<tr>
<td>$X_{102}$ Factor 2</td>
<td>0.003</td>
<td>0.001</td>
<td>.094</td>
<td>4.795**</td>
</tr>
<tr>
<td>$X_{104}$ Factor 4</td>
<td>0.068</td>
<td>0.050</td>
<td>.038</td>
<td>1.842</td>
</tr>
<tr>
<td>$X_{106}$ Factor 6</td>
<td>0.015</td>
<td>0.010</td>
<td>.045</td>
<td>1.974</td>
</tr>
<tr>
<td>$X_{109}$ Factor 9</td>
<td>0.254</td>
<td>0.191</td>
<td>.028</td>
<td>1.763</td>
</tr>
<tr>
<td>$X_{108}$ Factor 8</td>
<td>0.115</td>
<td>0.223</td>
<td>.007</td>
<td>0.269</td>
</tr>
<tr>
<td>$X_{103}$ Factor 3</td>
<td>-0.011</td>
<td>0.024</td>
<td>.004</td>
<td>0.216</td>
</tr>
<tr>
<td>C Constant</td>
<td>-4.110</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**.01 level of significance, 3.10 at 7, 42 degrees of freedom.

The prediction equation resulting from broken corn over 12/64th inch regressed on the factor variables was:

$$\hat{y}_b = -4.110 + 0.004X_{101} + 0.003X_{102} + 0.068X_{104} + 0.015X_{106} + 0.254X_{109} + 0.115X_{108} - 0.011X_{103}.$$ 

$H_{0.06}$: The slope of the regression line for percentage of broken corn over 12/64th inch was zero.

The analysis of regression for the previous equation yielded an F-value of 2.394 and was significant at the .05 level. The null hypothesis for the prediction of broken corn
over 12/64th inch was rejected. The prediction equation accounted for 28.5 percent of the variation of broken corn in the samples.

The standard error for predicting broken corn percentages with the six factor variables selected by regression was 1.164 percentages (Table 47).

Table 47. Stepwise regression of cracked, chipped and less than whole kernels on factor derived variables

<table>
<thead>
<tr>
<th>Source</th>
<th>d.f.</th>
<th>Mean square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>7</td>
<td>3.243</td>
<td>2.394*</td>
</tr>
<tr>
<td>Residual</td>
<td>42</td>
<td>1.354</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R^2 = 0.285$</td>
<td></td>
<td>Standard error = 1.164</td>
<td></td>
</tr>
</tbody>
</table>

*.05 level of significance, 2.24 at 7,42 degrees of freedom.

Stepwise regression of percentage of whole kernels with damaged pericarp on the factor variables was computed. The resulting regression coefficients for the variables selected by the regression technique are included in Table 48. Four factor variables contributed the major portion of the variance reduction attributable to the regression equation. They were: (1) factor 4 (.129), (2) factor 3 (.051), (3) factor 8 (.031), and (4) factor 6 (.031).

The resultant equation for predicting whole kernel with
Table 48. Regression coefficients of factor derived harvest variables for predicting percent whole kernels with damaged pericarp

<table>
<thead>
<tr>
<th>Variables</th>
<th>B</th>
<th>Std. error</th>
<th>$R^2$ change</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X_{104}$</td>
<td>Factor 4</td>
<td>1.518</td>
<td>0.645</td>
<td>.129</td>
</tr>
<tr>
<td>$X_{103}$</td>
<td>Factor 3</td>
<td>-0.302</td>
<td>0.302</td>
<td>.051</td>
</tr>
<tr>
<td>$X_{108}$</td>
<td>Factor 8</td>
<td>3.583</td>
<td>2.589</td>
<td>.031</td>
</tr>
<tr>
<td>$X_{106}$</td>
<td>Factor 6</td>
<td>0.204</td>
<td>0.135</td>
<td>.031</td>
</tr>
<tr>
<td>$X_{101}$</td>
<td>Factor 1</td>
<td>-0.013</td>
<td>0.021</td>
<td>.010</td>
</tr>
<tr>
<td>$X_{105}$</td>
<td>Factor 5</td>
<td>-0.082</td>
<td>0.179</td>
<td>.004</td>
</tr>
<tr>
<td>C</td>
<td>Constant</td>
<td>-29.484</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**.01 level of significance, 3.26 at 6, 43 degrees of freedom.

damage pericarp percentages was $\hat{Y}_w$ (percentage damage) =

$$- 29.484 + 1.518X_{104} - 0.302X_{103} + 3.583X_{108} + 0.204X_{106} - 0.013X_{101} - 0.082X_{105}.$$ 

$H_{057}$: The slope of the whole kernel regression line was zero.

Table 49 portrays the statistics needed to test the hypothesis. A significant F-value of 2.467 was observed and the null hypothesis was rejected. Twenty-five and six-tenths percent of the damage variation was explained by the variables described in Table 48.

The factor variables associated with percentages of
Table 49. Stepwise regression of whole kernels with damaged pericarp on factor derived harvest variables

<table>
<thead>
<tr>
<th>Source</th>
<th>d.f.</th>
<th>Mean square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>6</td>
<td>549.69</td>
<td>2.467*</td>
</tr>
<tr>
<td>Residual</td>
<td>43</td>
<td>222.82</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R^2 = 0.256$</td>
<td></td>
<td>Standard error = 14.927</td>
<td></td>
</tr>
</tbody>
</table>

*.05 level of significance, 2.32 at 6, 43 degrees of freedom.

sound kernel observations were investigated via stepwise regression computations. Data relative to the nature and extent of the associations are presented in Table 50. The factor variables exhibiting notable associations with lack of kernel damage as indicated by R-square change upon inclusion in the prediction equation were: (1) factor 4 (.133), (2) factor 3 (.053), (3) factor 8 (.034), and (4) factor 6 (.038). The resultant equation for predicting percentage of sound kernels $\hat{Y}_S$ was:

$$\hat{Y}_S = 128.923 - 1.585X_{104} + 0.302X_{103} - 3.812X_{108} - 0.216X_{106} + 0.010X_{101} + 0.080X_{105}.$$  

$H_{0:58}^T$: The slope of the regression line for percentage of sound kernels was zero.
Table 50. Regression coefficients of factor derived harvest variables for predicting percent sound kernels

<table>
<thead>
<tr>
<th>Variables</th>
<th>B</th>
<th>Std. error</th>
<th>$R^2$ change</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>X_{104} Factor 4</td>
<td>-1.585</td>
<td>0.641</td>
<td>.133</td>
<td>6.113**</td>
</tr>
<tr>
<td>X_{103} Factor 3</td>
<td>0.302</td>
<td>0.300</td>
<td>.053</td>
<td>1.010</td>
</tr>
<tr>
<td>X_{108} Factor 8</td>
<td>-3.812</td>
<td>2.574</td>
<td>.034</td>
<td>2.193</td>
</tr>
<tr>
<td>X_{106} Factor 6</td>
<td>-0.216</td>
<td>0.134</td>
<td>.038</td>
<td>2.616*</td>
</tr>
<tr>
<td>X_{101} Factor 1</td>
<td>0.010</td>
<td>0.021</td>
<td>.006</td>
<td>0.239</td>
</tr>
<tr>
<td>X_{105} Factor 5</td>
<td>0.080</td>
<td>0.178</td>
<td>.003</td>
<td>0.200</td>
</tr>
<tr>
<td>C Constant</td>
<td>128.923</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**.01 level of significance, 3.26 at 6, 43 degrees of freedom.

*.05 level of significance, 2.32 at 6, 43 degrees of freedom.

Analysis of variance of the regression equation was conducted resulting in the data contained in Table 51. An F-value of 2.623, significant at the .05 level, resulted in the rejection of $H_{0_{58}}$.

The standard error for the prediction equation was 14.8 percentages. The multiple correlation squared for regression was 0.268 (Table 51).

The percentage of germination as a measure of kernel damage was determined at the ISU Seed Laboratory for the corn samples. Stepwise regression of percent germination on factor variables results are reported in Tables 52 and 53.
Table 51. Stepwise regression of sound kernels on factor derived harvest variables

<table>
<thead>
<tr>
<th>Source</th>
<th>d.f.</th>
<th>Mean square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>6</td>
<td>577.709</td>
<td>2.623*</td>
</tr>
<tr>
<td>Residual</td>
<td>43</td>
<td>220.242</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>49</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$R^2 = 0.268$  Standard error = 14.841

*.05 level of significance, 2.32 at 6, 43 degrees of freedom.

Table 52. Regression coefficients of factor derived harvest variables for predicting percent germination

<table>
<thead>
<tr>
<th>Variables</th>
<th>B</th>
<th>Std. error</th>
<th>$R^2$ change</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>X_{105}</td>
<td>Factor 5</td>
<td>-0.518</td>
<td>0.155</td>
<td>.163</td>
</tr>
<tr>
<td>X_{103}</td>
<td>Factor 3</td>
<td>0.384</td>
<td>0.259</td>
<td>.038</td>
</tr>
<tr>
<td>X_{107}</td>
<td>Factor 7</td>
<td>-7.185</td>
<td>4.603</td>
<td>.034</td>
</tr>
<tr>
<td>X_{101}</td>
<td>Factor 1</td>
<td>0.019</td>
<td>0.018</td>
<td>.033</td>
</tr>
<tr>
<td>X_{108}</td>
<td>Factor 8</td>
<td>-1.971</td>
<td>2.290</td>
<td>.009</td>
</tr>
<tr>
<td>X_{109}</td>
<td>Factor 9</td>
<td>-1.451</td>
<td>2.126</td>
<td>.008</td>
</tr>
<tr>
<td>X_{106}</td>
<td>Factor 6</td>
<td>0.033</td>
<td>0.120</td>
<td>.001</td>
</tr>
<tr>
<td>C</td>
<td>Constant</td>
<td>0.586</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**.01 level of significance, 3.10, 7, 42 degrees of freedom.

*.05 level of significance, 2.24, 7, 42 degrees of freedom.
Table 53. Stepwise regression of germination on factor derived harvest variables

<table>
<thead>
<tr>
<th>Source</th>
<th>d.f.</th>
<th>Mean square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>7</td>
<td>404.073</td>
<td>2.423*</td>
</tr>
<tr>
<td>Residual</td>
<td>42</td>
<td>166.738</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>49</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$R^2 = 0.288$ Standard error = 12.913

*.05 level of significance, 2.24, 7, 42 degrees of freedom.

The order of variable selection and R-square change indicated in Table 52 provide information concerning factor damage relationships. The stronger relationships among variables and germination were: (1) factor 5 (.163), (2) factor 3 (.038), (3) factor 7 (.034) and (4) factor 1 (.033).

The following prediction equation accounted for 28.8 percent of germination variance as noted in Table 52. The equation was $\hat{Y}$

$$Y = 0.586 - 0.518X_{105} + 0.384X_{103} - 7.185X_{107} + 0.019X_{101}$$
$$- 1.971X_{108} - 1.451X_{109} + 0.033X_{106}.$$

Symbol $\hat{Y}$ signified the predicted percentage germination, X variables are identified in Table 52.

$H_{0,59}$: The slope of the regression line for the percentage of germination was equal to zero.

A test of the null hypothesis with the statistics provided in Table 53 resulted in the rejection of the null
hypothesis $H_0^g$. The F-value (Table 53) of 2.423 was significant at the .05 level with 7 and 42 degrees of freedom.

The equation for predicting percentage of germination accounted for 28.8 percent of the variation in germination percentage among the corn samples.

The regression of kernel damage following simulated handling treatment measured in percentage of fines was completed using factor variables. A second stepwise regression of kernel damage following simulated handling, was computed on factor variables with a subset of the samples. The results of stepwise regression of simulated handling damage on factor variables are indicated in Tables 54 and 55. The factor variables, in order of inclusion in the regression equation, the partial regression coefficients and the R-square change effected by the variable as it entered the equation are provided in Table 54. Factors 5, 1 and 3 in that order, with .083, .038 and .034 R-square changes respectively, constitute the independent variables for the prediction equation. The prediction equation was

$$\hat{y}_{f3} = 17.968 + 0.055X_{105} - 0.526X_{109} - 0.054X_{103}.$$ The symbol $\hat{y}_{f3}$ represents the percentage of fines following simulated handling of the corn samples. The X variables are listed in Table 54.

$H_0^g$: The slope of the regression line for percentage of fines was equal to zero.
Table 54. Regression coefficients of factor derived harvest variables for predicting percent fines after simulated handling

<table>
<thead>
<tr>
<th>Variables</th>
<th>B</th>
<th>Std. error</th>
<th>R^2 change</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>X_{105} Factor 5</td>
<td>0.055</td>
<td>0.025</td>
<td>.083</td>
<td>4.682**</td>
</tr>
<tr>
<td>X_{109} Factor 9</td>
<td>-0.526</td>
<td>0.334</td>
<td>.038</td>
<td>2.485</td>
</tr>
<tr>
<td>X_{103} Factor 3</td>
<td>-0.054</td>
<td>0.040</td>
<td>.034</td>
<td>1.855</td>
</tr>
<tr>
<td>C Constant</td>
<td>17.968</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**.01 level of significance, 4.24 at 3, 46 degrees of freedom.

Table 55. Stepwise regression of simulated handling percent fines on factor derived harvest variables

<table>
<thead>
<tr>
<th>Source</th>
<th>d.f.</th>
<th>Mean square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>3</td>
<td>13.033</td>
<td>2.815*</td>
</tr>
<tr>
<td>Residual</td>
<td>46</td>
<td>4.630</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R^2 = 0.155</td>
<td>Standard error = 2.152</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*.05 level of significance, 2.81 at 3, 46 degrees of freedom.
Data computed for the testing of the null hypothesis $H_{60}$ is displayed in Table 55. Based on a significant F-value of 2.815, the hypothesis $H_{60}$ was rejected. The prediction equation significantly accounted for 15.5 percent of the variation in fines with a prediction standard error of 2.152.

The damage measure, fines plus broken corn of less than whole kernel size, previously used as a damage measure for the analysis of variance of single categorized harvest variables and previously regressed on independent harvest variables, was also regressed on the factor variables. Tables 56 and 57 illustrate the results of broken corn regressed on factor variables. The factors selected by stepwise regression with the associated R-squares were (1) factor 9 (.074), (2) factor 2 (.080), (3) factor 4 (.040), (4) factor 6 (.027), and (5) factor 1 (.015). The resultant prediction equation was $\hat{\gamma}_{bc2} = -3.937 + 0.004X_{101} + 0.003X_{102} + 0.081X_{104} + 0.013X_{106} + 0.179X_{109}$. The predicted percentage of broken corn from factor variables was noted by $\hat{\gamma}_{bc2}$.

$H_{61}$: The slope of the broken corn regression line was equal to zero.

The F-value (2.708) resulting from the analysis of regression computations and recorded in Table 57 was significant at the .05 level and provided a basis for rejecting $H_{61}$. 
Table 56. Regression coefficients of factor derived harvest variables for predicting fines plus broken corn

<table>
<thead>
<tr>
<th>Variables</th>
<th>B</th>
<th>Std. error</th>
<th>$R^2$ change</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X_{101}$ Factor 1</td>
<td>0.004</td>
<td>0.002</td>
<td>.074</td>
<td>5.971**</td>
</tr>
<tr>
<td>$X_{102}$ Factor 2</td>
<td>0.003</td>
<td>0.001</td>
<td>.080</td>
<td>5.413**</td>
</tr>
<tr>
<td>$X_{104}$ Factor 4</td>
<td>0.081</td>
<td>0.052</td>
<td>.040</td>
<td>2.459*</td>
</tr>
<tr>
<td>$X_{106}$ Factor 6</td>
<td>0.013</td>
<td>0.011</td>
<td>.027</td>
<td>1.487</td>
</tr>
<tr>
<td>$X_{109}$ Factor 9</td>
<td>0.179</td>
<td>0.195</td>
<td>.015</td>
<td>0.844</td>
</tr>
<tr>
<td>C Constant</td>
<td>-3.937</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**.01 level of significance, 3.46 at 5, 44 degrees of freedom.

*.05 level of significance, 2.43 at 5, 44 degrees of freedom.

Table 57. Stepwise regression of fines plus broken corn on factor derived harvest variables

<table>
<thead>
<tr>
<th>Source</th>
<th>d.f.</th>
<th>Mean square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>5</td>
<td>4.193</td>
<td>2.708*</td>
</tr>
<tr>
<td>Residual</td>
<td>44</td>
<td>1.548</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>49</td>
<td>1.548</td>
<td></td>
</tr>
</tbody>
</table>

$R^2 = 0.235$ Standard error = 1.244

*.05 level of significance, 2.43 at 5, 44 degrees of freedom.
DISCUSSION

Much potential exists for increasing the value of Iowa's corn crop by reducing the extent of kernel damage associated with current practices of shelled corn harvesting. The reduction of handling, processing and quality losses are to a degree dependent on the physical quality of the corn kernel. Foreign importers of North American corn have expressed displeasure with the current physical appearance and quality of our corn exports.

More information, than presently available, should prove helpful to educators and combine operators in locating and reducing the losses presently associated with machine harvest of shelled corn.

Effort in this study was directed toward gaining a better understanding and increased knowledge concerning the factors associated with current practices in production of shelled corn as they relate to kernel damage. Benefits to the producer from the reduction of kernel damage must result without increased production costs, or increased losses from other sources, such as field loss of corn, beyond the benefits accruing to the production of higher quality shelled corn.

A sound basis for the application of educational effort to the solution of current problems is knowledge based on
the best evidence descriptive of the phenomena associated with the problems. The concerns of this study were the problem of corn harvest incurred damage, and complications resulting from that damage.

Findings indicate that kernel damage occurring at harvest post no problem at market time, however, the damage incurred at harvest appears to predispose corn to further breakage during commercial handling as indicated by the results of simulated handling treatment. A mean of 4.96 percentages of fines with a standard deviation of 2.42 percentages indicates commercial handling of corn requires screening to maintain corn grade. The broken corn over 12/64th inch size, while not recognized currently in grading practices, does present recognized problems in corn drying, aeration, appearance in export trade and reduced value of broken corn to corn processors. Percentage germination is a concern to seed corn producers. The mean germination of 72.66 with a standard deviation of 15.11 percentages indicated a need for better control of the harvest shelling process.

Agricultural engineers, alerted by seed corn producers, corn processors, foreign trade representatives and machine designers have been working on the damage problem as indicated by the efforts of Johnson and Associates (23), Waelti (42), Morrison (30), Hall (16), Kline (25) and others.
Findings of this study concerning the large percentage of kernel damage, unaccounted for by multiple regression analysis of the measured independent variables associated with corn harvest, indicated much more effort is required in the analysis of the nature of kernel damage; the stresses and forces the corn kernel is able to withstand; and the shape, construction and force imparting characteristics of the combine cylinder.

The results of analysis of variance for the vo-ag questionnaire item plus the inclusion of factor variables 3 and 6 in the equations for predicting percentages of fines after simulated handling, broken corn, whole kernel with damaged pericarp, and germination indicate, while minor in nature, a persistent association of learning by experience, education level, vo-ag training and operator age with the results of machine operation. Vocational agriculture teachers, agricultural extension personnel and area vocational technical teachers should utilize the expertise gained by combine operators through experience over time as resource persons in the teaching of high school vo-ag students; youth preparing for farming, and for implement sales and service careers; and in the educational classes and meeting for young and adult farmers.

A summarization of findings specific to the associations of operator experience and education suggest that, while the
predictability of kernel damage is highly variant, the observations indicate that the experienced operators (Tables 24, 37, 39, 46, 48, 54) had acquired the ability to make combinations of machine adjustments which appear to preserve substantial quantities of corn quality.

Presented in Table 58 is a summary of the significant relationships of independent variables to kernel damage at time of harvest.

The results of analysis of variance indicate no significant difference in damage due to machine make yet there appeared to be an association between machine design, or instruction for operation of specific machines, and the resulting product quality as indicated by the data in Tables 37, 41, and 56. Interpretation of the data in Tables 37, 41, and 56 indicate percentages of fines after simulated handling and broken corn varied a substantial 3 to 4 percent with combine make.

Instruction in the specifics of machine operation appear, based on interpretation of findings illustrated in Tables 35, 36, 37, 41, 46 and 56, of no special value in affecting kernel damage with the possible exception of cylinder speed. However, as inferred previously the author feels a knowledge on the part of the operator of what constitutes superior machine operation (kernel damage-wise) enables the operator to make combinations of adjustments that result in
Table 58. Summary of significant relationships of independent variables to damage measures

<table>
<thead>
<tr>
<th>Harvest Variables</th>
<th>Damage measures&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BC</td>
</tr>
<tr>
<td><strong>Agronomic</strong></td>
<td></td>
</tr>
<tr>
<td>Corn moisture content</td>
<td>0</td>
</tr>
<tr>
<td>Corn test weight</td>
<td>0</td>
</tr>
<tr>
<td>Corn standability (lodging)</td>
<td>-</td>
</tr>
<tr>
<td>Corn variety</td>
<td>0</td>
</tr>
<tr>
<td>Row space in inches</td>
<td>0</td>
</tr>
<tr>
<td>Yield per acre</td>
<td>0</td>
</tr>
<tr>
<td><strong>Machine</strong></td>
<td></td>
</tr>
<tr>
<td>Combine make</td>
<td>0</td>
</tr>
<tr>
<td>Concave clearance, front</td>
<td>0</td>
</tr>
<tr>
<td>Concave clearance, rear</td>
<td>0</td>
</tr>
<tr>
<td>Cylinder speed</td>
<td>+</td>
</tr>
<tr>
<td>Ground speed</td>
<td>0</td>
</tr>
<tr>
<td>Harvest rate, bu. per hour</td>
<td>+</td>
</tr>
<tr>
<td>Harvest rate, bu. per cyl. inch</td>
<td>0</td>
</tr>
<tr>
<td>Header size, rows</td>
<td>0</td>
</tr>
<tr>
<td><strong>Operator</strong></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>0</td>
</tr>
<tr>
<td>Experience, years</td>
<td>0</td>
</tr>
<tr>
<td>Experience, acres per yr.</td>
<td>0</td>
</tr>
<tr>
<td>Farming status</td>
<td>0</td>
</tr>
<tr>
<td>Frequency of machine adj.</td>
<td>0</td>
</tr>
<tr>
<td>Post-h.s. vo-ag classes</td>
<td>0</td>
</tr>
<tr>
<td>Source of knowledge</td>
<td>0</td>
</tr>
<tr>
<td>Years schooling</td>
<td>0</td>
</tr>
<tr>
<td>Years h.s. vo-ag</td>
<td>0</td>
</tr>
</tbody>
</table>

<sup>a</sup>BC = broken corn, > 12/64th inch < whole kernel; BC<sub>T</sub> = total broken corn < whole kernel; W<sub>d</sub> = whole kernel damage with damaged pericarp; S = sound kernels; F<sub>sh</sub> = fines following simulated handling; G = germination; 0 = no significant relationship established; - = negative relationship; + = positive relationship; s = significant effect, direction not meaningful.
higher quality shelled corn. Therefore the instruction of machine part functions, machine-crop dynamics, and a knowledge of what constitutes superior harvesting performance, would appear to be valuable assists toward the reaping of the benefits associated with less kernel damage.

The area of agronomics has provided a number of interrelated associations between practice and kernel damage for consideration. The importance of crop moisture had been established by earlier investigations and holds true in this study. Moisture effects on damage, however, present problems that must be overcome by means other than waiting with harvest operations until corn moisture content is ideal. Other problems, timeliness of field operations, and size of farm operations, will rarely allow harvest damage control based on corn moisture content.

Corn test weight, while indicating strong associations with kernel damage tended to be closely related to corn moisture, and similarly limited in control due to more important considerations than kernel damage.

Findings associated with variety and test weight provide implications for education in seed selection, in controlling corn grain characteristics through genetics, in proper plant nutrition, and in pest control. The interpretation of findings presented in Tables 15, 37 and 52 suggest
variety selection may affect broken corn percentages by two percentages.

Custom combine operators and farmers must be aware of the benefits to be gained from the harvesting of corn of high physical quality, and of those factors affecting corn quality variations. Special programs or workshops conducted prior to corn harvest time, arranged by vocational agriculture teachers and/or extension personnel, are means of getting the message to combine operators. Clinics in which combine operators can participate in the actual adjustment of the combine needed to minimize corn damage, and maximize field shelling efficiency, will result in many dollars of added value to the corn producer. Educational programs, in addition to providing instruction in machine adjustment, must inform farmers concerning the associated corn production practices that contribute to increased value of the corn crop. The importance of variety selection, row spacing, crop nutrition, and the rate of harvesting per cylinder inch are vital subjects for discussion. A recognition of the effect of kernel damage to the corn economy along with agronomic practices, machine adjustments and field operational practices associated with corn quality, will without doubt prove profitable to farmers and custom operators alike.

Knowledge without application is nonproductive and of questionable value. The findings indicate farmers rely on
machinery dealers, servicemen and operator's manuals for a good share of their knowledge. Vocational and technical schools; university mechanized agriculture departments; and extension personnel are in an excellent position to prepare and upgrade the competencies of present and future machinery dealers, servicemen, and machine company employees, to the role they have in helping farmers improve their corn harvesting performance. The knowledge needed by these persons is very similar to that needed by the machine operators.

The organization and implementation of educational efforts as suggested, requires the preparation of educational leaders who understand the specific problems and interactions of man and machine. They must teach, or assemble resources for teaching, the necessary knowledge and skills to develop competence in machine operations and an understanding of the interacting factors as revealed to by this study.

Research and educational resources and manpower to prepare educators in an adequate manner can best be supplied by competently staffed colleges of agriculture through their departments of agricultural education, agricultural mechanics or engineering, agronomy and economics. Inservice education for vocational agriculture teachers, area vocational-technical instructors, and extension specialists should be provided to update these men concerning the latest information
available.

The value of this study will be maximized when: (1) operators of corn combines recognize the benefits of harvesting shelled corn of high physical quality, understand the effect of proper cylinder speeds, concave clearances and harvest rates, make the proper adjustments as needed, consider the influence of corn variety, and combine make on corn quality; (2) when farmers recognize the relationship of corn quality to the value of the crop, appreciate the value of experienced and knowledgable machine operation, consider the effect of and seek appropriate corn varieties, and maximize the benefits to be gained by harvesting at reduced moisture and maximum corn test weight; (3) when educators of farmers, future farmers, present and future machinery dealers and servicemen utilize experienced and competent resource persons for teaching machine operation and adjustment, and stress the value of quality corn processing and associated factors to their students; (4) when engineers establish more completely the parameters associated with mechanical ear corn shelling, and design more effective shelling mechanisms; (5) when dealers and machinery servicemen recognize the importance of their role in providing assistance to combine operators in proper adjustment and operation of the machines they sell, and base their advice on an understanding of the interaction of machine
adjustments and crop conditions; (6) when plant breeders and seed producers design and produce corn varieties that minimize shelling damages; and (7) when teacher educators seek knowledge and work across subject disciplines to assist students in developing understandings of the interrelationship of factors affecting kernel damage.
SUMMARY

The purpose of this study was to determine the relationship of selected agronomic, harvest machine operator, and harvest machine operational characteristics to harvest incurred damage to shelled corn.

Assistance in conducting this study was provided by the USDA Agricultural Research Service, Iowa State University Unit, and Market Quality Research Division Laboratory, Manhattan, Kansas; Iowa State University Agricultural Engineering and Agricultural Education Departments; National Corn Growers Association; Iowa Development Commission; Iowa Agricultural Marketing Board; Farmers Grain Dealers Association of Iowa; USDA Consumer and Marketing Service, Grain Division Laboratory, Des Moines, Iowa; and participating elevator managers and individual farmers.

A list of factors potentially affecting the degree of harvest damage to shelled corn was formulated. Agronomic, operator and harvest machine operational characteristics associated with those factors, not ascertainable from the corn sample, were selected and used to develop a questionnaire for collection of data to accompany each shelled corn sample. Sampling efforts resulted in the accumulation of 209 usable corn samples and 171 usable questionnaires.

Corn samples were analyzed to ascertain the desired physical properties at Iowa State Seed Laboratory, Ames,
Data descriptive of the corn samples and of the corresponding questionnaire information were coded and placed on IBM cards. The data were treated to yield number of responses per questionnaire item, distribution and frequency of item responses, means, and standard deviations for each questionnaire items.

All variables were treated by Pearson product-moment correlation. Correlation results were considered in the selection of the most appropriate corn damage measures, and to identify the nature and extent of inter-variable associations.

The three measures of corn damage selected for extensive use were: (1) percentage of broken corn less than 12/64th inch size and foreign matter; (2) percentage of broken corn over 12/64th inch size, but less than whole kernels; and (3) percentages of fines less than 12/64th inch and foreign matter determined following simulated handling treatment. Percentage of broken corn less than 12/64th inch and foreign matter was combined with percentage of broken corn over 12/64th inch size, but less than whole kernel size, to create one of two measures of damage applied in all computations.
The second measure applied in all calculations was broken corn and foreign matter less than 12/64th inch size, following simulated handling of the corn samples. The remaining measures of kernel damage were treated selectively as dependent variables for specific statistical treatment.

Analysis of variance, single classification, was used to determine the presence or absence of a significant linear relationship between the independent agronomic, operator or operational, harvesting variables and two selected indicators of corn damage.

The voluntary nature of the information gathering technique resulted in missing data for a variety of questionnaire items. The mean kernel damage for the samples corresponding to each answered and unanswered questionnaire item were grouped as respondent and nonrespondent classes, and tested to establish the presence or lack of homogeneity among the corn samples. No significant differences in kernel damage were noted among respondents and nonrespondents, except that those respondents who supplied information concerning vocational agriculture class enrollment had significantly less broken corn in their samples regardless of the amount of vocational agriculture participation.

Analysis of variance treatment of the individual independent variables indicated six variables possessed significant relationships to the degree of kernel damage in the
corn samples. The six items were: (1) corn moisture at harvest time, (2) test weight per bushel, (3) crop standability, (4) harvest rate in bushels per cylinder inch per 10 hours, (5) cylinder speed, and (6) adjusted cylinder speed.

Further investigations of the direction and magnitude of the effect of independent variables in combination on kernel damage were concluded via stepwise regression. A prediction equation, significant at the .05 level, for each of three kernel damage measures resulted from the stepwise regression computations.

The prediction equations explained only a minor portion of the kernel damage variations observed in the corn samples. The percentage of variation in kernel damage explained by each of the three prediction equations as indicated by the multiple correlation squared, was: 37.1 for broken corn less than whole kernel size, 25.3 for sound kernels, and 18.9 for the fines following simulated handling. The low percentage of damage variation accounted for by the predictor variables gave an indication of: (1) the relative uncontrollable nature of phenomena of kernel damage, within the shelled corn harvesting processes studied, (2) a probability of a number of predictor variables not included in the study, (3) a lack of precision in variable measures, and/or (4) the random nature of shelling kernel damage.
Those predictor variables that accounted for most of the prediction value of the regression equation were: (a) combine make, corn variety, harvest rate in bushels per cylinder inch per 10 hours, cylinder speed, and corn test weight, accounting for 72 percent of the value of the broken corn prediction equation; (b) operator years of combining experience, combine make, rear concave clearance, frequency of machine adjustment, and harvest rate in bushels per cylinder inch per 10 hour, accounting for 75 percent of the value of the sound kernel prediction equation; and (c) test weight, bushels per cylinder inch per 10 hours, combine make, and header size, accounting for 79 percent of the value of the fines following simulated handling prediction equation.

Factor analysis of the independent variable data established commonalities of variance among the predictor variables. The variable groupings by commonalities were: (1) yield per acre, machine header size, harvest rate in bushels per hour, harvest rate in bushels per cylinder inch per 10 hours, and operator acres of combining experience; (2) cylinder speed, and adjusted cylinder speed; (3) crop standability, operator years of combining experience, and corn variety based on mean broken corn per variety; (4) corn row spacing, and combine make, based on mean broken corn per make; (5) corn moisture content, and test weight; (6)
age of operator, and years high school vo-ag; (7) operator farming status, and source of operating knowledge; (8) front and rear concave settings; (9) harvest machine ground speed.

Predictor variables resulting in no unique pattern of variance, nor strong commonalities of variance with other factors were: (1) adult or young farmer class membership, (2) years of schooling, (3) frequency of machine adjustment, and (4) mechanical interest and ability rating of the operator.

The results of factor analysis were applied in the construction of a second set of predictor variables. Stepwise regressions of the constructed variables on seven criterion variables: (1) percentage fines, (2) percentage of broken corn less than whole kernel more than 12/64th inch, (3) percentage of whole kernels with damaged pericarp, (4) percentage of sound kernels, (5) percentage germination, (6) percentage of fines following simulated handling, and (7) percentage of broken corn less than whole kernel size were computed.

This series of stepwise regression computations was conducted with data from a subset of samples accompanied by questionnaires containing complete information for all items. The stepwise regression of the seven kernel damage measures on the constructed variables indicated the following significant relationships: (1) fines, or BCFM - no signifi-
cant relationship to the constructed variables; (2) broken corn more than 12/64th inch less than whole kernel - significantly related to constructed variable 1 (yield per acre, machine header size, harvest rate in bushels per cylinder inch, operator experience in acres per year), and to factor 2 (cylinder speed and adjusted cylinder speed); (3) whole kernels with damaged pericarp - significantly related to constructed variable 4 (corn row spacing, combine make identified by mean broken corn for that make); (4) sound kernels - significantly related to constructed variable 4 (corn row spacing, combine make), and to constructed variable 6 (operator age, years of schooling, years high school vo-ag); (5) germination - significantly related to constructed variable 5 (corn moisture content, test weight), and to constructed variable 7 (operator farming status, source of operating knowledge); (6) fines following simulated handling - significantly related to constructed variable 5 (corn moisture content, test weight); (7) broken corn less than whole kernel - significantly related to constructed variable 9 (harvest machine ground speed), to variable 2 (cylinder speed, adjusted cylinder speed), and to variable 4 (corn row space, combine make).

The statistical revelations of this study are contained in the following summary statements:
1. Frequencies, means and standard deviations descriptive of agronomic, machine operator and machine operational variables associated with field practice of shelled corn harvesting were determined.

2. Respondents and nonrespondents to individual questionnaire items had comparable harvest kernel damage with the exception, respondents to the vo-ag class enrollment question had significantly less kernel damage than nonrespondents.

3. Analysis of variance treatment of the data indicated significant differences in kernel damage associated, under field conditions, with three agronomic factors (corn harvest moisture content, corn test weight and crop standability), and with three machine operational factors (harvest rate in bushels per cylinder inch, cylinder speed, adjusted cylinder speed).

4. Commonalities among harvest variables based on variance patterns were established.

5. Data descriptive of the extent and direction of the association of corn harvest variables, in combinations common under field practices, with corn kernel damage were computed.

6. A maximum of 37.1 percent of the variation among corn samples in percentage of broken corn, of less than whole kernel size, could be explained by the variables studied.
7. Significant prediction equations, based upon the variables studied, were developed for estimating the influence of production and harvesting practices on the following damage measures: broken corn less than whole kernel and over 12/64th inch size, whole kernels with damaged pericarp, sound kernels, germination, BCFM following handling, and broken corn less than whole kernel size.

8. The damage measure BCFM was not predictable using the variables studied.

The reduction in kernel damage in harvesting of shelled corn is one means of reducing financial losses occurring in marketing channels, and of increasing the value and the demand for the corn crop.

Custom combine operators and farmers must be aware of the benefits they can gain from the harvesting of corn of high physical quality, and the association of those factors under their control. Special programs or workshops conducted prior to corn harvest time, arranged by vocational agriculture teachers and/or extension personnel with assistance from machinery dealers are means of informing combine operators.

Vocational and technical schools; university mechanized agriculture departments; and extension personnel are in an excellent position to prepare and upgrade the competencies
of present and future machinery dealers, servicemen, and machine company employees, for the role they have in helping farmers improve their corn harvesting efficiency.

Inservice education for vocational agriculture teachers, extension personnel and vocational-technical instructors should be provided to update these men concerning the latest information and practices associated with efficient corn harvest.


34. Patry, James Dean. Farm machinery competencies needed for employment in production agriculture and farm machinery dealerships in Ellsworth county. Unpublished M.S. report. Manhattan, Kansas, Department of Agricultural Education, Kansas State University. 1971.


40. Tugend, David Martin. Comparative study of selected farm mechanical skills performed by successful Maryland farm operators and farm mechanics. Unpublished M.S. thesis. College Park, Maryland, Library, University of Maryland. 1964.


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CORN HARVEST QUESTIONNAIRE

Purpose: The above organizations are conducting a study of the effect of harvesting and drying practices on corn quality. The identity of operators and owners will not be disclosed. Your cooperation in completing this questionnaire will be greatly appreciated.

1. Corn
   (a) Variety__________________________
   (b) Estimated yield_________ bu/acre

2. Combine
   (a) Make__________________________
   Model__________________________
   (b) Corn head, no. of rows____
       spacing of rows______ inches
   (c) Cylinder speed_________ rpm
   (d) Concave clearance: Front____
       inches Rear______ inches
   (e) Speed of travel:_________ miles per hour

3. Harvest
   (a) Average harvest rate:_________ bu/hour
   (b) Corn standability:
       Mostly upright_____ Some lodging____
       Lodging over 25%____

4. Machine Operator
   (a) Age group: (circle)
       Less than 25, 25-34, 35-44, 45-54, 55-64, 65 and over
   (circle)
   (b) Highest grade schooling________
   (circle)
   (c) Years of Voc. Agr. 0, 1, 2, 3, 4; young farmer class, adult class
   (circle)
   (d) Type of operator: own machine; hired man; custom operator;
       other____________________
   (e) Operating experience: years_____; acres per year_____
   (f) Check your main source or sources of operating know-how
       _____ Experience
       _____ Educational meetings
       _____ Training by experienced operator
       _____ Machinery dealers or service men
       _____ Study machine manual
       _____ Magazine articles
   (g) Check your normal machine adjustment frequency
       _____ Once a day
       _____ 3 times a day
       _____ Twice a day
       _____ Several times a day
   (h) Rate your mechanical interest and ability
       _____ low
       _____ medium
       _____ high