HERITABILITIES AND ASSOCIATIONS BETWEEN SOME AGRONOMIC CHARACTERS IN A TWO-ROW x SIX-ROW BARLEY CROSS

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DONALD WILLIAM BRAY

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APPROVAL:

[redacted]

Professor of Farm Crops

In Charge of Major

[redacted]

Head of Department of Farm Crops

[redacted]

Chairman of School Graduate Committee

[redacted]

Dean of Graduate School

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INTRODUCTION

Barley is an important crop in most cultivated areas of the world. However, because of its wide distribution, locally adapted varieties are often required for profitable farming and specialized industrial use.

High yield of good quality barley is dependent on many plant characteristics, chief among these being vigor, tillering, maturity, and resistance to diseases, insects, drought and lodging. Most of the important agronomic characters of barley are inherited in a complex manner, and little is known about their exact inter-relationships. This is principally the result of the difficulty in classifying the number of factors influencing these characters. It is important to have a knowledge of the inter-relationships between factors for desired plant characteristics when a hybridization and selection program is being designed. These inter-relationships can be studied in an F_2 population through calculation of correlation coefficients, and X^2 tests for independence.

Heritability estimates are useful in determining the heritable portion of the total variation observed, and in predicting progress possible from selection. If the heritability estimate for a particular plant character is low, then most of the variation observed in that character is caused by environmental effects. In this case, gains from selection would be relatively slow. Where heritability estimates are higher, progress through selection may be made relatively more rapidly.

One of the problems breeders of cereal crops have to face is determining a reliable and practical method of measuring lodging resistance on a single plant basis, particularly in segregating populations. This problem of measuring lodging resistance is complicated by annual environmental variation, and also variation between locations, to which lodging is very responsive. Therefore, it would be desirable to know something about the heritability of this character, and its possible association with other agronomic plant characters.

This experiment was designed to study the heritability and association of characters in a cross of six-row x two-row spring barleys. Variances of the parental, F_1, and F_2 generations were calculated and used to determine heritability estimates. Correlation coefficients and X^2 tests for independence were used to study associations between the characters measured.

LITERATURE REVIEW

Head Type

Hayes et al. (32, p. 88-102), reviewing reports of two-row x six-row crosses in barley, reported that the F_1 generation is most frequently intermediate in head type, and the F_2 segregates into one six-row type to two intermediate, to one two-row. Other studies showed two factors (one for six-row, and one for *intermedium* hypostatic to the six-row factor). Minor modifying factors were thought to be present which influenced the degree of fertility of the lateral florets. Woodward (60, p. 320-322) in a comprehensive study, found considerable variability in lateral floret fertility from plant to plant, and between heads on the same plant. Several of the *intermedium*-type plants with numerous lateral kernels showed a significantly higher percentage of lateral kernels when spaced farther apart in the row.
Lambert et al. (38, p. 365) reported that a two-row parent contributed factors which tended to reduce seed setting in the lateral spikelets. Full sized lateral kernels were not recovered in the F_4 generation of six-row type selections from two-row x six-row crosses. Both Wexelsen (56, p. 314-315) and Griffee (24, p. 919-922) found only a single factor pair determining two-row vs. six-row types. However, Wexelsen noted modifying factors which affected the degree of fertility in heterozygous plants, and a continuous range from six-row to two-row in an F_2 population.

Neatby (46, p. 78), in a two-row x six-row cross found a ratio of one six-row type to three other types, in the F_2 generation. The intermediates observed, ranged from those with almost complete lateral floret fertility, to those with only one fertile lateral floret. Some lateral florets were well developed, but sterile, and these heads were classified as two-row types. Fraser (14, p. 113) found the two-row type dominant over the six-row type but noted disagreement in the literature over the completeness of this dominance. Fraser likewise described a two-row x six-row cross studied by Dr. C. E. Saunders, where almost all classes from two-row to almost perfect six-row types appeared in the F_2. In the F_3 however, these almost perfect six-row types acted as true intermediates, segregating about 25 per cent two-row, 50 per cent like the parent, and 25 per cent six-row.

Tiller Number

Yield of grain is a complex character, affected by several components, chief among these being number of tillers, number of kernels per head, and kernel weight. Kumler (37, p. 3-7) reviewed the literature on tillering and noted the great range in tillering observed by many workers when environmental conditions were manipulated. Kumler found disagreement on the relation of tillering to yield. However, many authors believed good tillering ability a distinct advantage in producing better yielding varieties. Kumler (37, p. 50-52) found the six-row low tillering types out-yielded the two-rowed high tillering varieties.

Kumler also reported a highly significant positive correlation between number of tillers and yield.

Lambert _et al_. (38, p. 368) in a study of various characters in the F_4 generation of six-row segregates from a two-row x six-row barley cross, reported a highly significant negative correlation coefficient of -0.363, for seeds per head, and heads per row. Clark _et al_. (10, p. 571) showed no correlation between tillering and lodging in wheat. Wiklund (58, p. 551) found more tillers and greater yield in two-row x six-row barley crosses to have a high positive correlation with the two-row type in the F_2 generation. Fiuzat _et al_. (13, p. 417) obtained heritability estimates of 29.5 per cent and 23.6 per cent for number of tillers in the F_2 generation of two barley crosses. Welton _et al_. (55, p. 48,56) found that in fields of wheat and oats, most of the lodged plants had more and larger culms.

Plant Height

Several investigators have reported significant positive correlation coefficients for plant height and yield in wheat (7, p. 114; 11, p. 43; 12, p. 63; 19, p. 584; 31, p. 901; 52, p. 383), while Waldron (53, p. 135) found no correlation between these characters. Torrie (52, p. 383) suggested these contradictory results were due to the use of different materials, grown under widely differing environment conditions.

McKenzie (43, p. 247), Harlan *et al.* (28, p. 22) and Leasure *et al.* (39, p. 373), found a significant correlation between plant height and yield in barley. Goulden (19, p. 584) showed a significant negative correlation of plant height and straw-strength in wheat, as did Norden *et al.* (48, p. 338), in oats. Wiklund (58, p. 551) found that in a two-row x six-row barley cross, the two-row hybrids often had longer straw than did the two-row parent. Fiuzat *et al.* (13, p. 417) and Frey (17, p. 187) calculated broad-sense heritability values for plant height in barley. The values ranged from 44 per cent to 75 per cent. Jogi (36, p. 295) found narrow-sense heritability estimates for plant height which ranged from 59 per cent to 77 per cent in three crosses of barley.

Lodging

Harlan *et al.* (27, p. 308) stated that stiff straw is the prime objective of the cereal breeder attempting to produce lodging resistant varieties. Harlan also pointed out that stiff straw is not the only answer, since lodging may be caused by a number of factors, and some slender, tough culms lodged less than did some stiff erect ones. Mulder (45, p. 248) in a review of the literature on lodging in cereals, explained apparent contradictions in the literature as being due to the effects of environmental factors on the many characters contributing to lodging resistance. Lodging in cereals was the result of a combination of adverse weather, and an inadequate standing ability of the plants. This lack of standing ability may be caused by a weakness in the lower internodes, or by inadequate anchorage of the plants in the soil in proportion to the weight of the upper plant. Hamilton (25, p. 674) found that most bending occurred between ground level and the first node in oats. Patterson (49, p. 518) observed that bending at the upper node, "node bending," may occasionally be a factor in lodging. Welton (55, p. 6) stated that lodging may be a result of two sets of causes: (1) Interaction of hereditary and environmental factors which result in weak stems, (2) External forces having no influence on stem structure, but causing lodging through mechanical impact (wind, rain, etc.,). Lodged wheat and oats were always found in ravines, or depressions, suggesting higher levels of water and nutrients as being environmental variants. Atkins (3, p. 70) pointed out that lodging in cereals is dependent upon a number of factors which show wide annual fluctuation, thereby making it difficult to establish a reliable index for prediction purposes. Lodging resistance is a varietal characteristic (9, p. 25-26) but environmental variation exercises a direct influence.

Murphy et al. (44, p. 609) found several strains of oats with superior lodging resistance in the world oat collection. Frey (18, p. 535) stated that since some varieties have greater lodging resistance than do others, it can be assumed that these differences are genetic in origin. Frey reviewed reports by

Indian workers who found one gene pair responsible for lodging resistance in rice, with resistance "strongly dominant." Boyce (5, p. 79-81) presented data showing a single gene causing pronounced weakness in a wheat cross. Torrie (52, p. 375-376) reported lodging resistance in spring wheat to be inherited as a quantitative character. Frey (18, p. 537) suggested that lodging resistance (tested by Grafius' cLr method 23, p. 416) is genetically controlled to some extent.

Nelson (47, p. 611-612) noted that seasonal variations in incidence and degree of lodging often make it difficult to evaluate lodging resistance. For this reason, a mechanical tool enabling a standardized estimate of lodging resistance, regardless of incidence of natural lodging, would be very useful. This has led many workers to investigate various mechanical methods of testing lodging resistance (23, p. 416; 20, p. 263; 34, p. 118-120; 39, p. 370-371; 45, p. 246-252; 43, p. 246; 50, p. 74-75; 55, p. 8-9; 59, p. 334-335). Most of these methods are time consuming, and highly subject to environmental variation. Nelson (47, p. 612) used mature culms in a device to measure straw breaking strength. Bartel (4, p. 155) studied changes in breaking strength in wheat straw, concluding that major differences in breaking strength of varieties of comparable maturity could be determined at any time. Atkins (2, p. 118) suggested that the low correlation between breaking strength and lodging may be due to the numerous factors determining straw strength as well as there being a lack of data on lodging. Clark (10, p. 571) reported data showing the inaccuracy of the assumption that breaking strength of the culm and lodging resistance are synonymous. Grafius (23, p. 416) suspended a chain of known weight per link from the base of an oat panicle. By counting the number of links of chain the culm would support, converting this to grams, and dividing by the height in centimeters, a coefficient of lodging resistance "cLr" was determined. Good repeatability was observed, both several days later, and on other culms in the same row. A highly significant negative correlation of cLr data with actual lodging was also noted. Murphy et al. (44, p. 116) found the snap test for lodging resistance more heritable than the cLr. In the snap test, several plants in a row are manually bent over, released, and their degree of recovery observed. Frey et al. (18, p. 536) showed the snap test to be more heritable, easier, and quicker, than the cLr method, although requiring more experience to be reliable. Frey also stated that the snap test cannot be used on individual plants where use of the cLr method becomes obligatory. Frey found a heritability estimate of 19 per cent for cLr in oats.

Jogi (36, p. 295) calculated narrow sense heritability values in three barley crosses, and found heritability estimates for yield to be 61, 64 and 60 per cent. For lodging per cent, heritability estimates were 42 and 60 per cent, and for lodging resistance heritability estimates were 77, 40 and 83 per cent.

Atkins (2, p. 118) studying the relationships of certain plant characters to strength of straw in wheat, found weight per unit length of straw better than breaking strength of straw. This was still not satisfactory as an index of lodging resistance, since correlation with actual lodging was not significant. These low correlations between breaking strength and lodging are caused by the numerous factors determining straw strength, and because there is a lack of data on what really causes lodging. Brady (6, p. 224-231) showed that strong-strawed varieties of oats possessed certain morphological characteristics which are associated with straw strength to a significantly greater degree than did weak strawed ones. These characteristics were tillering, height, internode length, diameter of internodes, thickness of culm wall, number of vascular bundles, width of lignified tissue in cross-section, and thickness of the walls of the sclerenchyma cells. It was also noted that all these characteristics were so subject to environmental variation, that their use as an index of lodging resistance would be possible only on a relative basis. Hamilton (26, p. 292-295) studied varieties of oats known to differ widely in lodging resistance, and found them to be different in culm, crown, and root characteristics as well. Varieties with high lodging resistance had crowns of greater diameter, larger, more rigid culms, and widely spreading coronal root development. Frey _et al._ (18, p. 535) reviewed work on the inheritance of characteristics associated with lodging in barley, where the amount of sclerenchyma tissue was determined by two genes. The radial width of the sclerenchyma band, and the diameter of the tangential and radial axes of the vascular bundles were inherited as quantitative characters. Smith (51, p. 24) found low correlation between the F_2 and F_3 generations in oats for breaking strength of straw. The correlation for culm diameter was also low. Harrington (30, p. 59) in testing resistance to lodging in cereals, found good correlation between number of coronal roots and lodging resistance, but no correlation between lodging and any other plant measurement. Hamilton (25, p. 670) devised an index for lodging resistance combining height and diameter at the second internode from ground level. Caffrey _et al._ (9, p. 30-31, 34-35) reported no stem characteristics (tillering, height, diameter, and internal structure) in oats were sufficiently independent of the environment to act as an index of straw strength. However, strong-strawed varieties were found to have better root systems. Norden _et al._ (48, p. 338) found large culm diameter and large cross sectional area of stem tissue showed a "sizeable common association" with lodging resistance in oats. Norden suggested that since the cLr and plant height are negatively correlated, a breeder need simply select for shortness, and lodging resistance would be achieved simultaneously. This may be limited because shortness appears to be associated with lower yields. Perhaps breeders may progress best by holding height constant at a level consistent with good yields, and selecting for lodging resistance within this group.

Yield

Yield of grain is a complex characteristic, depending on several plant characters among which inter-relationships can fluctuate with environmental variation. Grafius (22, p. 256) found the narrow sense heritability estimate for yield in an F_2 barley generation to be 4.6 per cent. In a later paper, Grafius (21, p. 553) reported correlation coefficients between heads per plant, seeds per head, and weight per seed, were low or zero, concluding there are no genes for yield *per se*, only for the components. Hence he postulated that yield is an artifact, and cannot have a heritability. Wiklund (58, p. 551) reported that in two-row x six-row barley crosses, tillering and yield showed a high positive correlation with the two-row type. Fiuzat (13, p. 417) found heritability estimates of 51 and 44 per cent for yield in two F_2 barley populations. Frey *et al*. (17, p. 187, 543) found narrow-sense heritability estimates of 59 per cent for yield in one experiment, and of 39 per cent in another.

Heritability Estimations

Heritability estimations are useful to plant breeders in predicting progress that might be expected from a selection program. Hayes *et al*. (33, p. 496) noted that if a plant character is not subject to environmental variation, heritability estimates would be expected to be high. However, if the plants do not differ greatly in genetic factors conditioning differences in the character, then the heritability estimate for that character will be low, and environmental variance will be of prime importance. That is, if there is no genetic variance, no progress can be made through selection.

Mahmud et al. (42, p. 608) calculated heritability in a soybean experiment by using $\sqrt{\sigma_{P_1}^2 \cdot \sigma_{P_2}^2}$ as an estimate of the environmental variance. The symbols P_1 and P_2 were used to designate the two parents. Burton (8, p. 415) used the variance of the F_1 as an estimate of the environmental variance. Allard (1, p. 32-34) used $\frac{V_{P_1} + V_{P_2} + V_{F_1}}{3}$ as an estimate of environmental variance for heritability calculations.

Frey (16, p. 545) stated that heritability calculations have two uses: (1) In estimating, in a biological population, the proportion of total variation which is heritable, (2) In predicting gains possible from selection. Frey et al. (17, p. 187) stated that with low heritabilities the plants for the particular character being studied, are largely environmentally influenced. Lerner (40, p. 155) pointed out that if heritability is low, progress in selection is slow and difficult. If, however, heritability is high, progress may be easy and rapid.

Correlations

In selection programs, cereal breeders are often concerned with associations between the characters being studied. Frequently an important character, such as lodging resistance is difficult to measure, or evaluate, particularly on a single plant basis in segregating populations.

Occasionally this character is found to be associated with others, some of which are more readily measurable. The breeder then can direct his efforts toward the task of selecting for the easily evaluated character, and be confident of making satisfactory progress toward his main goal at the same time. Estimates of the possible association between characters of a plant are therefore useful, and are provided by correlation studies.

Hsi *et al*. (35, p. 470) stated that in a breeding program designed to develop barleys of improved agronomic and malting value, a proper balance of characters must be maintained in selections. When correlating the F_5 and F_6 generations of a barley cross, Hsi *et al*. found highly significant coefficients of 0.43 for plant height, and 0.56 for yield.

Atkins (3, p. 70-71) calculated correlations between F_2 wheat plants, and their F_3 progenies, finding $r = 0.58$ for culm diameter, $r = 0.40$ for breaking strength, $r = 0.61$ for weight per unit length, and $r = 0.69$ for plant height. It was suggested that with correlation coefficients this high, selection for these characters can be made in early generations, and that continued selection would lead to the desired types.

Burton (8, p. 415) found that with a large population, a correlation coefficient as low as 0.14 was statistically significant. However, combinations of characters opposite to those indicated by the correlation coefficients could easily be found in the F_2 populations where $r = 0.40$. Leasure et al. (39, p. 373) discussed numerically low, but statistically significant correlation coefficients, pointing out that they are of little value in a selection program.

Method of Planting

Weiss et al. (54, p. 795) found that yield from an F_2 spaced plant was determined largely by environmental factors. Several workers have reported experiments wherein various plant spacings have been used. Fiuzat (13, p. 415) used four inches between plants within the rows, Frey (18, p. 535) used one foot between rows, eight inches between plants, and Grafius (21, p. 551) used one foot between plant and rows. Harrington (29, p. 604) found that 18 inches between rows probably masked some differences in performance, but removed border effects sufficiently that border rows and guard plants were unnecessary. This allowed much more efficient use of limited amounts of seed, such as usually are available in F_1 or backcross generations.

MATERIALS AND METHODS

Two spring barley varieties were used as parents in a study of the heritabilities and associations between the following important characters: head type, number of kernels per head, number of tillers per plant, plant height, straw strength and yield of grain per plant. The varieties used as parents for this cross are described as follows (57, p. 208-210, 125):

1. Hannchen (C.I. 531) a selection from Hanna made at the Plant Breeding Station, Svalof, is a two-row variety with weak to moderately stiff straw, mid-tall in height. It has medium tillering and yield capacities, and large plump kernels ranging in weight from 32-45 mg. per kernel.

2. Harlan (C.I. 7008) selected from a composite cross by H. V. Harlan and others at Aberdeen, Idaho, is a six-row variety with short, stiff straw. It is low in tillering ability, yield is high and kernel weight ranges from 42-50 mg. per kernel.

Hannchen was used as the male parent in these crosses to produce the F_1 seeds. The crosses were made in the research greenhouses at Oregon State University during the winter of 1958-59. The F_1 seeds were planted in the greenhouse, and the F_2 seeds harvested from the F_1 plants during the summer of 1959. In 1960 the two parents, and the F_1 and F_2 populations were grown in a randomized block design with four replicates, at the East Farm, Corvallis, Oregon.

There was one row per replicate of each of the parents, and of the F_1. The identity of the seeds used to produce the F_2 families was recorded, and the seed from a single F_1 plant was bulked to form an F_2 family. There were 41 of these F_2 families with sufficient seeds to plant one row in each of the four replicates.

The seeds were planted six inches apart in rows fifteen feet long, and eighteen inches apart. An oat plant was used as a single guard plant at the ends of each row and a row of oats was seeded to serve as guard rows at the ends of each replicate. The plot area was fertilized uniformly with 50 pounds of nitrogen in the form of ammonium nitrate as a top dressing, and was irrigated once during the growing season. Weeds were controlled by hand cultivation to maintain as uniform an environment as possible for the barley plants. The aphid vector of yellow dwarf virus was controlled by twice-weekly spray applications of Malathion. These applications were started at the time of emergence of the barley plants, and continued until danger of yellow dwarf infection was over.

Experimental Design

The field lay-out was in the form of a randomized block, with four replicates, but the data were analyzed as a completely randomized experiment, because of the problem of replicating the F_2 families.

There were 41 F_2 rows, one row each of the two parents, and one row of the F_1 generation, making a total of 44 rows or entries per replicate, each with 30 seeds planted. In many rows, one or more plants did not emerge, or were later damaged, or destroyed by pheasants, disease, or other uncontrollable accidents. To facilitate statistical calculations, data were not recorded from entries with fewer than 23 mature plants per row in each of the four replicates. This reduced the number of families used in the F_2 population to 33. The 33 F_2 families, one F_1 and two parents, composed the 36 entries per replicate. All rows were brought to a uniform number of 23 plants per row by randomly omitting enough plants from those rows having more than this number of mature plants.

Measurements

Measurements for each of the six characters were made as follows:

1. Head type. Heads of each plant were noted as to whether they were two-row or six-row in type. Some of the F_1 and F_2 plants were difficult to classify as to head type. Some of the lateral spikelets seemed almost large enough to be classified as fertile, whereas others were very much reduced in size, yet appeared to be fully fertile with well developed endosperm. These were classed as intermediate in head type.

2. Tillers per plant. Only tillers that had heads with mature kernels were counted.

3. Plant Height. The tallest culm of each plant was measured in centimeters from ground level at the base of the plant, to the lowest node of the head.

4. Kernels per head. The number of kernels in the head borne on each culm that was measured for plant height were counted.

5. Straw strength. The culm measured for plant height was used to measure straw strength by the hanging chain method developed by Grafius. There was considerable variability in straw strength between plants in the F_2 generation, and a large difference between the parents. A very light chain of 0.071 grams per link was used to pull the weak to moderately stiff stems toward the ground sufficiently to determine a cLr (coefficient of lodging resistance). The stiffer segregates were often able to support this chain without bending over at all. In addition to the chain, extra weights were suspended at the base of the spike of these stiff stems until they bent over to an angle of approximately 45 degrees with the ground.

Lodging coefficients (cLr) were determined on 28 randomly selected plants of each of the parents and of the F_1. The F_2 population was sampled by determining 28 coefficients from each of the 33 F_2 families.

6. Yield of grain per plant was difficult to determine because of varying amounts of head-loss during harvest, storage, during drying and threshing. The plants in each row were grouped according to head type prior to threshing in bulk. Then average weight per head for the two-row plants in each row was determined by dividing the total weight of seed from the two-row plants in a row by the number of two-row heads in that row. This average weight of seed per head was then multiplied by the number of heads produced by each two-row plant in the row, to arrive at an estimate of yield per plant. Similarly, yield per plant was estimated for the six-row plants in each row.

Methods of Analysis

Frequency distributions were constructed in both tabular and graphic form for each character measured in the P_1, P_2, F_1, and F_2 generations. Genetic variances and broad-sense heritabilities were calculated using the methods outlined by Allard (5, p. 105-107). The variance of the F_2 population ($\sigma^2_{F_2}$) is assumed to be a combination of genetic (σ^2_G) and environmental (σ^2_E) variances. The variances of the three non-segregating populations ($\sigma^2_{P_1}$, $\sigma^2_{P_2}$ and $\sigma^2_{F_1}$) should consist almost entirely of environmental variance. An estimate of σ^2_G would be provided by subtracting the variance of any of the non-segregating populations from that of the F_2. There may be some difference between the variances of the non-segregating populations due to minor environmental differences within each row. For this reason an average of these three variances should give a better estimate of the σ^2_E.

The formulae used for estimating genetic variance (σ^2_G), and heritability (H), were as follows:

$$\sigma^2_G = \sigma^2_{F_2} - \sigma^2_E \quad \text{where} \quad \sigma^2_E = \frac{\sigma^2_{P_1} + \sigma^2_{P_2} + \sigma^2_{F_1}}{3}$$

$$H = \frac{\sigma^2_{F_2} - \sigma^2_E}{\sigma^2_{F_2}}$$

Where σ^2_G = genetic variance

$\sigma^2_{F_2}$ = variance of the F_2 population

σ^2_E = environmental variance

$\sigma^2_{P_1}$ = variance of the P_1 population

$\sigma^2_{P_2}$ = variance of the P_2 population

$\sigma^2_{F_1}$ = variance of the F_1 population

H = heritability (broad sense) estimate.

Data for each character measured were subjected to an analysis of variance, and the method of individual degree of freedom (41, p. 226-233) was used to determine whether differences between entries were significant. Inthe analysis of variance calculations, the degrees of freedom for the error term were determined by multiplying the number of replicates minus one times the number of treatments minus one. The number of replicates was four in most cases, and three in the others. The number of treatments was 36, composed of the following: two parents, one F_1, and 33 F_2 families. A X^2 test for goodness of fit (33, p. 452-456) was applied to the F_2 data for segregation for head type, and a X^2 test for independence was applied to several of the possible combinations of characters. Correlation coefficients (41, p. 265-268) were calculated for most of the possible combinations of the characters measured.

EXPERIMENTAL RESULTS

Analyses of variances, genetic variances, heritabilities, correlations between characters, and X^2 tests of association and independence, for tillering, kernels per head, plant height, straw strength and yield, were calculated and reported in this study.

Since the parental and F_1 generations are non-segregating, they should have relatively similar variances for any particular character measured. In this study there was great disparity in the variances exhibited by these non-segregating generations. The order of these differences was not consistent. The variance of tillering of the F_1 generation was similar to the variance of the six-row parent, but quite different from that of the two-row parent. For plant height, the variance of the F_1 was similar to that of the six-row parent, but different from the variance of the two-row parent. The variance of the lodging coefficient of the F_1 generation was similar to that of the two-row parent, but different from that of the six-row parent. It is postulated that these differences may be accounted for by a rather sensitive genotype x environment interaction.

Allard (1, p. 32-34) used an average of the variances of the three non-segregating generations for the purpose of calculating genetic variance. The data Allard used in the example showed only minor differences between the respective variances.

In the present study, rather large differences between the variances of the non-segregating generations were found. However, because a better method was not available, Allard's method of determining the environmental variance was used to calculate the heritability estimates reported.

Head Type

The spike on the tallest culm of each plant was used for the head type classification. Of the 3036 F_2 plants examined, 1877 were classified as two-row types, and 999 were six-row types. The remaining 160 were classed as intermediate, but were included with the two-row group before the data were subjected to a X^2 test for goodness of fit to a 3:1 ratio (Table 1). The probability for a X^2 value of 101.2 with one degree of freedom indicates a poor fit of the data to a 3:1 ratio.

Table 1. SEGREGATION OF HEAD TYPE IN THE F_2 GENERATION: X^2 TEST FOR GOODNESS OF FIT TO A 3:1 RATIO.

Phenotype	Observed Number	Calculated Number	O - C	$\frac{(O - C)^2}{C}$
Two-row	2037	2277	-240	25.3
Six-row	999	759	+240	75.9
Total	3036	3036	0	$X^2 = 101.2$

P for 1 d. f. $<$ 0.005

Head type appears to be mainly influenced by a single gene pair, with the two-row type being dominant. Modifying factors are present however, resulting in slight, although confusing variations in the segregating generations. The F_1 heads were two-row type, although the lateral florets were slightly enlarged. This gave the heads a rounder, fuller appearance than that of the two-row parent, although none of these laterals were fertile, and none were observed to shed pollen. These variations made clear-cut classification of F_2 plants according to head type difficult. Incidence of lateral floret fertility seemed to be highly influenced by environment. In some F_2 plants, the tallest, or first formed culms were definitely two-row types, whereas the later formed heads on the shorter culms of the same plant were intermediate in appearance. That is, they were two-rowed, with a varying number of fertile lateral florets. Some of these very late formed heads, so immature at harvest time that very little or no endosperm had formed, were fully six-row types in appearance. Occasionally an F_2 plant of the six-row type was found having from one to several sterile lateral florets. These variations were more in evidence among the two-row type F_2 plants, than among the six-row types.

It is perhaps for these reasons, that there is confusion with regard to inheritance of head type in barley. In the present experiment, the poor fit to a simple 3:1 phenotypic ratio might be explained by the difficulty in classification of the intermediate types. There were few F_2 plants which exhibited a clear cut two-row head type. Many had some characteristics of the six-row type in one or more heads. It frequently was necessary to make quite arbitrary decisions as to whether sufficient lateral florets were fertile, or seemingly so, to be considered an intermediate, or parental type. This possibly resulted in too high a frequency in the recessive class.

Analysis of Variance

The analyses of variances are summarized and grouped in Table 2. The generations were compared with each other by means of the single degree of freedom.

1. Tillering. In this analysis, all comparisons made were significantly different, except for that of the F_1 with the F_2 generations. The large mean square for the comparison of the parents is indicative of the large difference in tillering ability between these varieties. The comparisons made between the two-row parent (P_1) and the F_1 and F_2 generations, had larger mean squares than did the same comparisons made with the six-row parent. This is borne out by an examination of Figure 1 and Table 3, where it is seen that the plants of the two-row parent produced more tillers than did the plants of the six-row parental, the F_1, or the F_2 generations. In Figure 1, the peaks of the curves for the F_1 and F_2 generations coincide closely with that of the six-row parent, suggesting the dominance of the lower tiller number of the six-row parent.

Table 2. SUMMARY OF MEAN SQUARES OBTAINED FOR FIVE CHARACTERS OF A TWO-ROW x SIX-ROW BARLEY CROSS.

Variation Due to:	Degrees of Freedom	Mean Squares				
		Tillers Per Plant	Kernels Per Head	Plant Height	Straw Strength	Yield Per Plant
Replication	3	672.73*	260.95[1]	886.15*	3.97*	861.87*
P_1 vs. P_2	1	4792.34*	20942.03*	2468.89*	48.88*	33.51
P_1 vs. F_1	1	1836.10*	887.68	8009.76*	0.10	5.28
P_2 vs. F_1	1	695.75*	30452.90*	19372.52*	20.12*	12.18
P_1 vs. F_2	1	1625.40*	8490.36*	843.48	0.63	95.13
P_2 vs. F_2	1	777.57*	11986.02*	9657.19*	25.18*	2.85
F_1 vs. F_2	1	3.80	17863.38*	9148.98*	1.52*	42.91
Error	105	176.36	612.02[1]	368.30	0.21	225.84

* Denotes significant at the 5 per cent level.

[1] Degrees of freedom for Rep. = 2, and for error = 70.

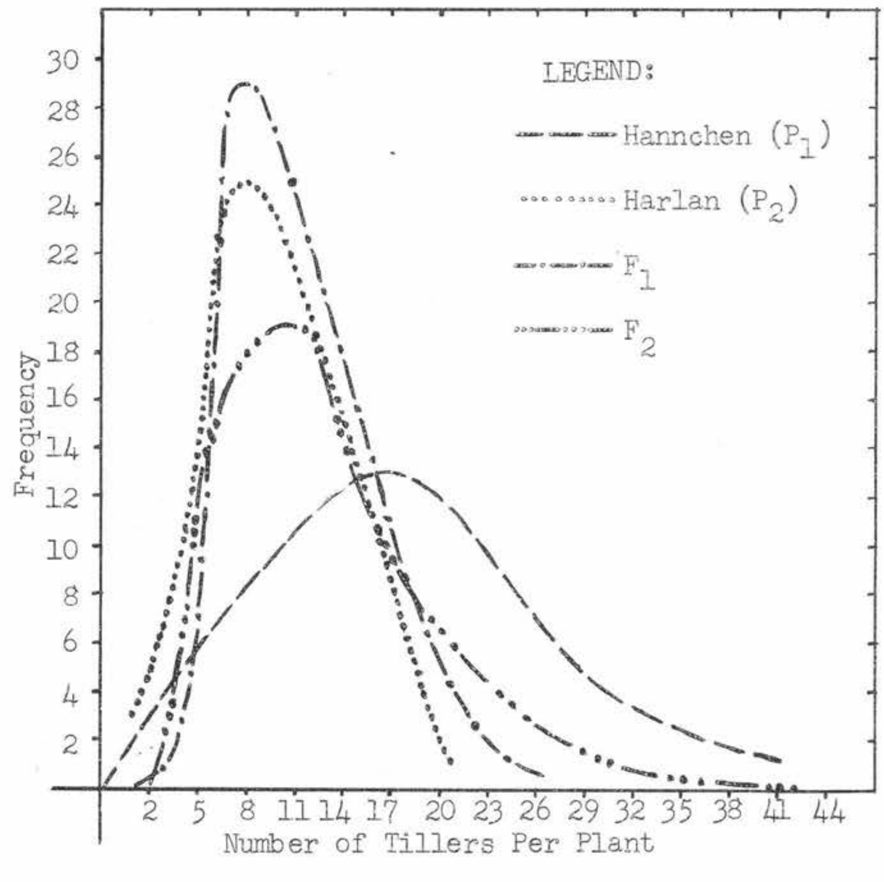

Figure 1. FREQUENCY DISTRIBUTION OF NUMBER OF TILLERS PER PLANT.

The means of the F_1 and F_2 generations (Table 3) were not significantly different from each other, and were somewhat below the midparent value of 13.6. This also suggests some degree of dominance for fewer tillers per plant. However, it may be inferred from the relative nearness of the F_1 and F_2 means to the mid-parent value, that a part of the genetic variance for tillering is additive.

Table 3. MEANS, VARIANCES, AND COEFFICIENTS OF VARIABILITY, FOR TILLERS PER PLANT.

Generation	n	Mean	C.V.	Variance
P_1 Hannchen	92	17.2	37.44	64.4
P_2 Harlan	92	10.0	17.30	17.3
F_1	92	12.7	16.77	21.3
F_2	3036	12.9	30.69	39.6

2. Kernels per head. In the analysis of variance for kernels per head (Table 2) all the comparisons were significantly different, except for the two-row parent with the F_1 generation.

The parents had a significantly different number of kernels per head (Table 2). The dominance of the lower number of kernels of the two-row parent is indicated by the lack of significant difference between the P_1 and F_1 generations. The comparison of the six-row parent with the F_1 generation had greater mean squares than had the same comparison made with the two-row parent. This indicates that the number of kernels per head in the F_1 generation was more nearly like that of the two-row parent, which had fewer kernels per head than did the six-row parent.

The six-row parent had many more kernels per head, and a much higher variance than did the two-row parent (Table 4 and Figure 2). In the F_1 generation, over-dominance for fewer kernels per head is suggested. However, the F_2 generation segregated into two groups with means of 27.4, and 74.4 kernels per head. These groups corresponded to those segregating for head type. The F_2 plants with six-row type heads had many more kernels per head than did those with two-row type heads.

Table 4. MEANS, VARIANCES, AND COEFFICIENTS OF VARIABILITY FOR KERNELS PER HEAD.

Generations	n	Mean	C.V.	Variance
P_1 Hannchen	69	31.6	2.31	7.3
P_2 Harlan	69	56.3	8.98	50.6
F_1	69	26.6	6.24	16.6
F_2	2277	42.9	1221.21	523.9

The large variance of the F_2 generation (Figure 2) is a result of the great spread in the distribution of this generation. The right hand peak is much broader, thus contributing greatly to the variance. This broader distribution was largely a result of variation in head length. Some heads, regardless of row number, were much shorter than others. The longer heads often had longer

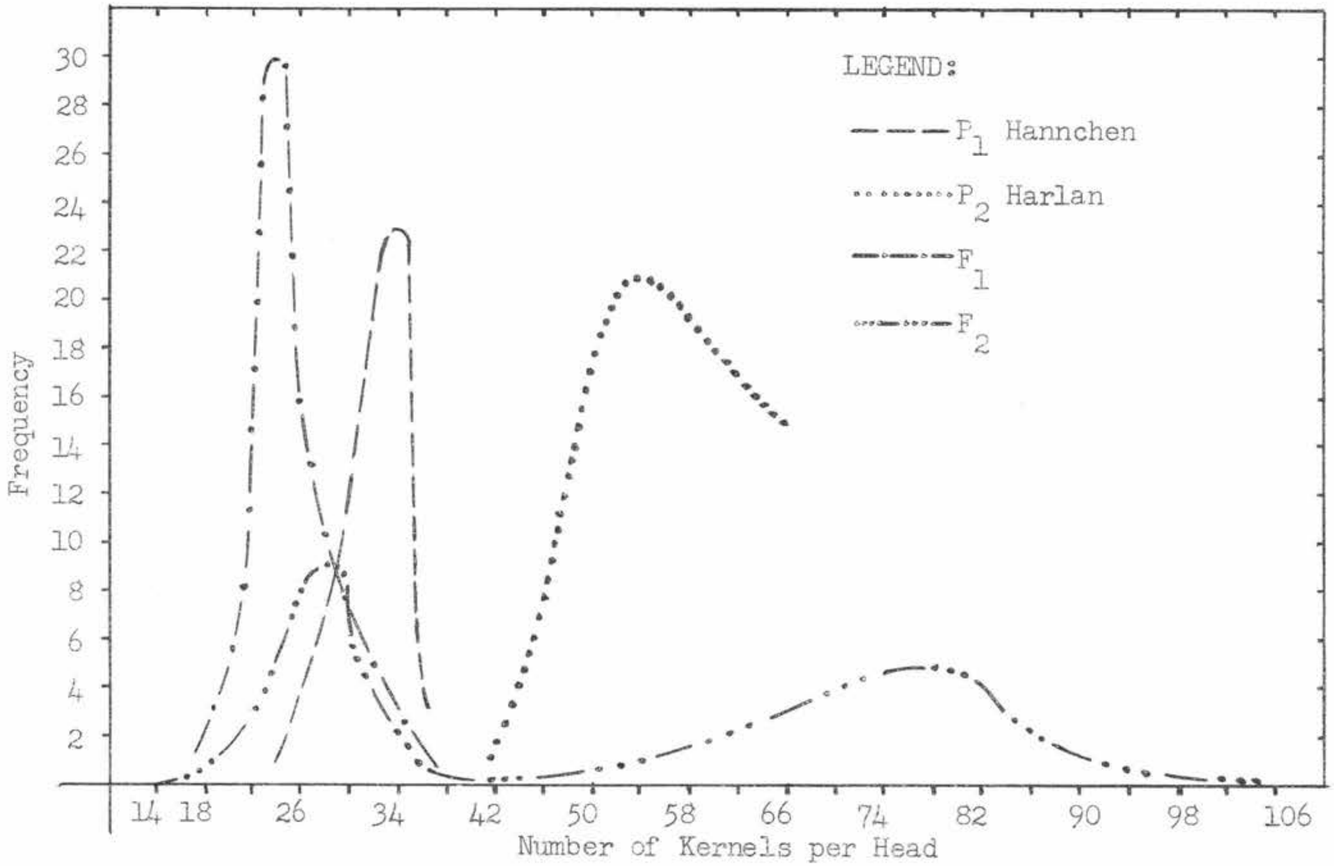

Figure 2. FREQUENCY DISTRIBUTION OF KERNELS PER HEAD.

internodes, but usually had more nodes as well, consequently had more kernels per head.

3. Plant Height. Plant height of barley has been shown to be conditioned by several genes, and to be rather highly influenced by the environment.

All comparisons made in the analysis of variance (Table 2) showed significant differences except for the comparison of the two-row parent with the F_2 generation. The two-row parent was significantly taller than the six-row parent (Tables 2 and 5, and Figure 3). The F_1 generation was taller than the parental and F_2 generations.

Plant height appeared to exhibit some over-dominance in this cross, since the mean height for the F_1 plants exceeded that of the taller parent by 20 per cent. The height of the F_2 generation was not significantly different from that of the taller two-row parent (Table 2), although the mean of the F_2 generation was only slightly above the mid-parent height.

Table 5. MEANS, VARIANCES, AND COEFFICIENTS OF VARIABILITY FOR PLANT HEIGHT.

Generations	n	Mean	C.V.	Variance
P_1 Hannchen	92	66.64	13.63	90.84
P_2 Harlan	92	59.32	6.36	37.72
F_1	92	79.84	4.79	38.26
F_2	3036	63.99	14.57	93.23

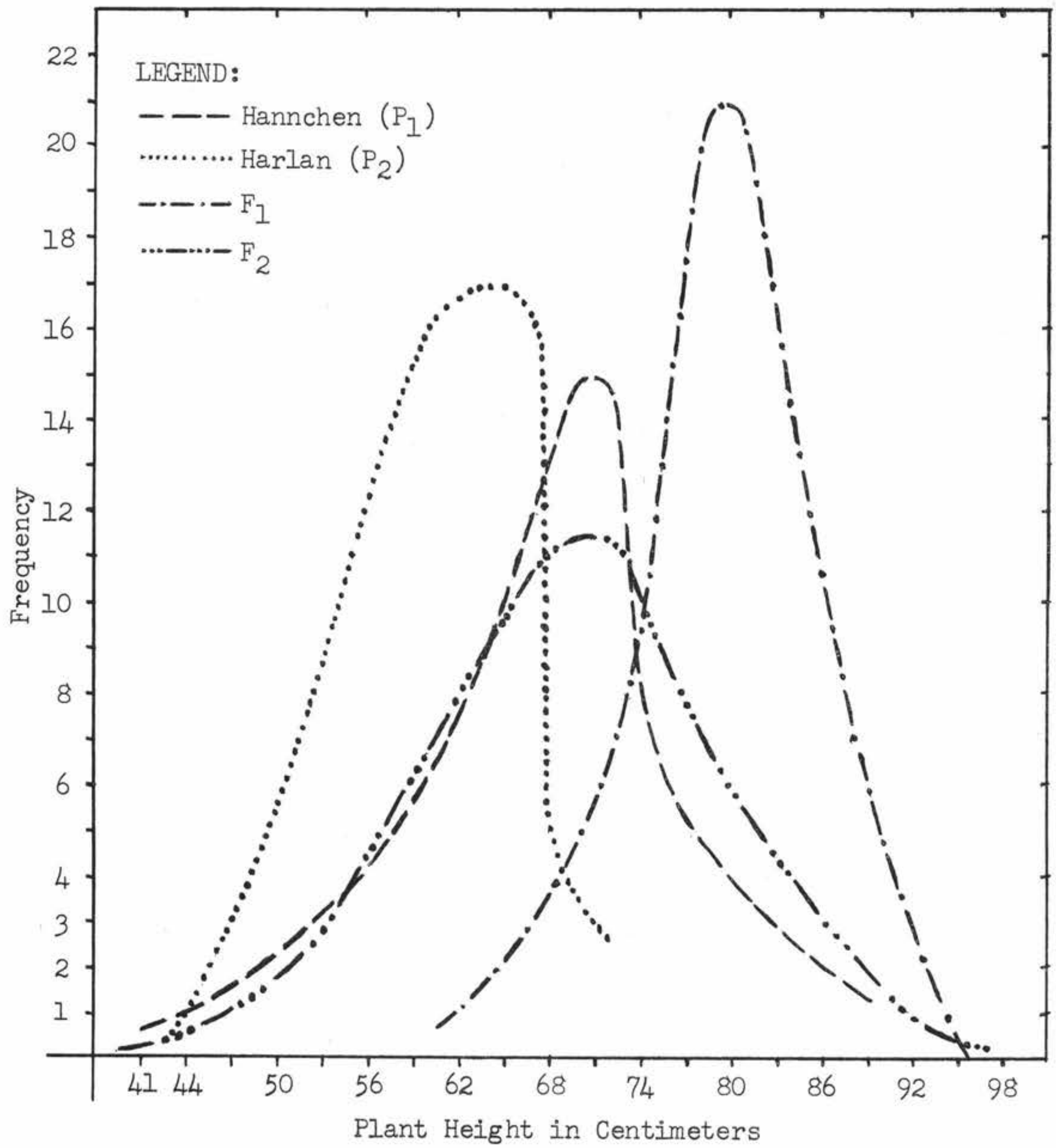

Figure 3. FREQUENCY DISTRIBUTION OF PLANT HEIGHT.

4. <u>Straw Strength (cLr)</u>. In the analysis of variance for straw strength (Table 2), differences were significant for all comparisons, except for the two-row parent with the F_1 and F_2 generations.

The six-row parent had stronger straw than did the two-row parent (Table 6). The dominance of the weaker straw of the two-row parent is indicated by the lack of a significant difference in straw strength between the two-row parent and the F_1 generation, and between the two-row parent and the F_2 generation.

The mean coefficient of lodging resistance for the stiffer strawed six-row parent was greater than twice that of the weaker strawed two-row parent (Table 6, and Figure 4). The mean lodging coefficient of the F_1 generation was less than that of either parent, suggesting some overdominance for weaker straw. The mean of the F_2 generation was only slightly greater than that of the two-row, or weaker parent, but far less than the mid-parent value of 1.57. This suggests that most of the genetic variance is non-additive.

Table 6. MEANS, VARIANCES, AND COEFFICIENTS OF VARIABILITY FOR STRAW STRENGTH (cLr).

Generations	n	Mean	C.V.	Variance
P_1 Hannchen	28	1.01	10.30	0.104
P_2 Harlan	28	2.13	13.94	0.297
F_1	28	0.93	6.77	0.063
F_2	924	1.16	110.21	1.300

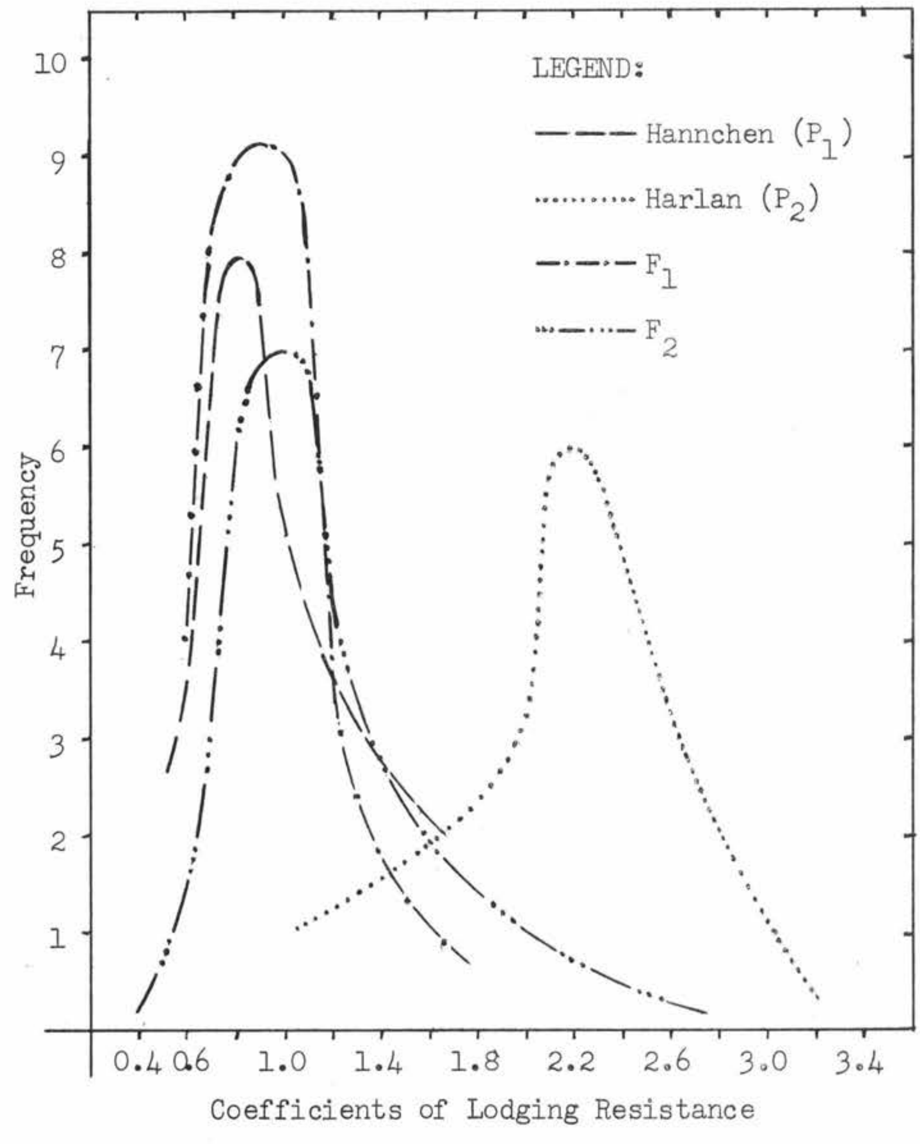

Figure 4. FREQUENCY DISTRIBUTION OF STRAW STRENGTH (cLr).

5. Yield per plant. There were no significant differences between the generations with respect to yield (Tables 2 and 7 and Figure 5). Although there was a significant difference between replicates, there was none between any of the combinations of the parental, F_1 and F_2 generations.

Table 7. MEANS, VARIANCES, AND COEFFICIENTS OF VARIABILITY FOR YIELD PER PLANT.

Generations	n	Mean	C.V.	Variance
P_1 Hannchen	92	13.40	28.61	38.34
P_2 Harlan	92	14.26	24.99	35.64
F_1	92	13.74	17.24	23.69
F_2	3036	14.43	85.43	123.27

Genetic Variances and Heritabilities

Genetic variances and "broad sense" heritability estimates for tillers per plant, kernels per head, plant height, straw strength, and yield are shown in Table 8.

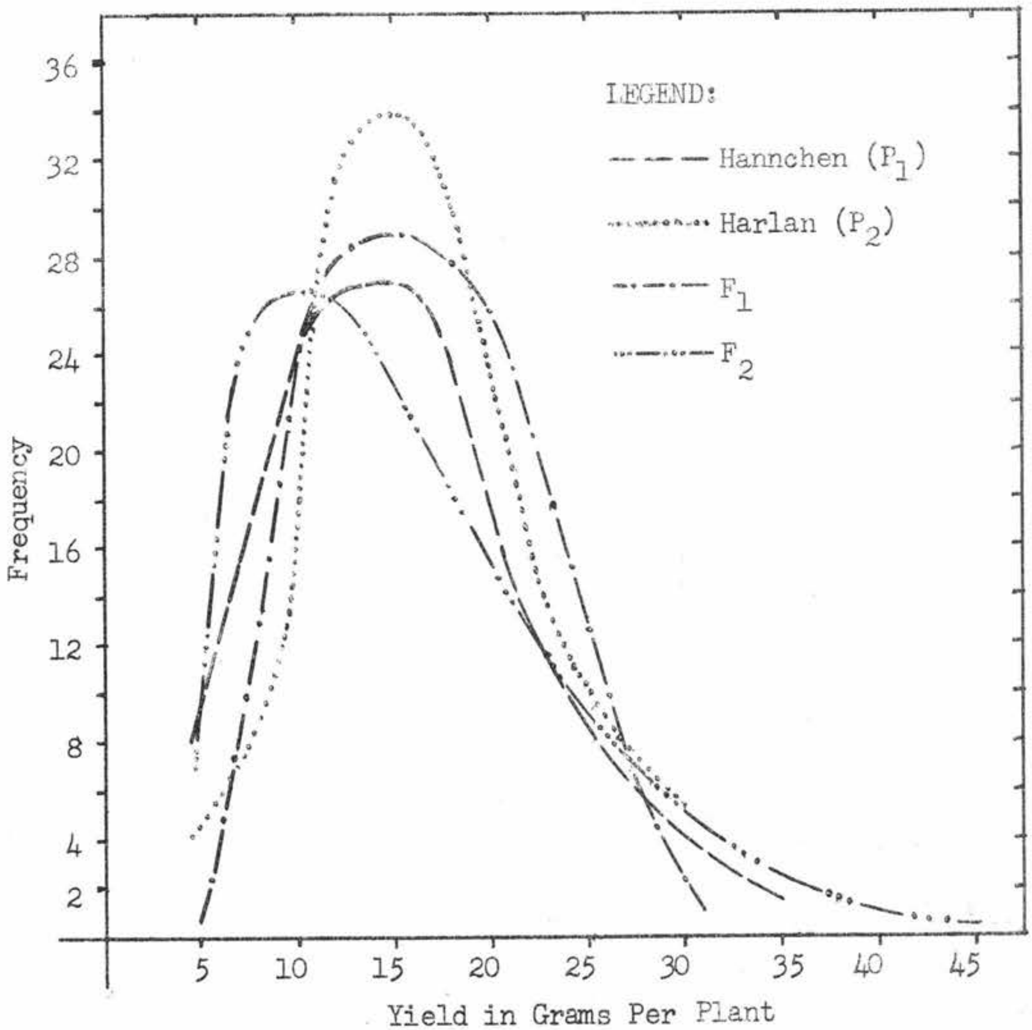

Figure 5. FREQUENCY DISTRIBUTION OF YIELD OF GRAIN PER PLANT.

Table 8. GENETIC VARIANCES OF THE F_2 GENERATION, AND BROAD SENSE HERITABILITY ESTIMATES FOR THE CHARACTERS STUDIED.

Character	Genetic Variance	Per Cent Heritability Estimates
Tillers per plant	34.31	13
Kernels per head	499.08	97
Plant height	55.61	40
Straw strength (cLr)	0.16	88
Yield per plant	90.71	74

Tillering is a character of cereals that is highly influenced by the environment. The occurrence of second growth in cereal crops subjected to late season moisture, and the observed continued production of new tillers in greenhouse plantings, are evidence for this environmental effect. In this study, the low genetic variance and heritability estimate, suggest that most of the variation in tillering was environmental, and that little progress would be made by selection for this character.

The number of kernels per head is a function of the number of nodes per head and the number of kernels per node. The number of kernels per node determines the head type in barley, and is a feature of the genotype, not the environment. In contrast, the number of nodes in the head is influenced by the environment, resulting in some variation in number of kernels per head. The high heritability estimate for number of kernels per head in this study indicates the low effect of the environment on this character.

It also indicates that good progress would be made by selection for number of kernels per head.

Lodging resistance as measured by straw strength, showed a high heritability estimate, which indicates that selection for stiff-strawed barleys would be possible in this material.

There was no difference in yield between the parents or between any comparison of the parents with the F_1 or F_2 generations. The shattering and head loss which occurred prior to threshing, made it necessary to calculate estimates of yield per plant for use in heritability computations. The calculation of yield per plant probably reduced the variability between plants, and a relatively high heritability estimate for yield was a result.

Correlations

Simple correlations were calculated for all possible combinations of the characters measured, and are presented in Table 9.

Table 9. SIMPLE CORRELATION COEFFICIENTS FOR ALL POSSIBLE COMBINATIONS OF CHARACTERS MEASURED.

Characters Measured	n	Kernels Per Head	Plant Height	Straw Strength (cLr)	Yield
Tillers per plant	3036	0.08**	0.48**	-0.08**	0.99**
Kernels per head	3036		0.01	0.004	0.34**
Plant Height	3036			-0.38**	0.09**
Straw Strength (cLr)	924				-0.06

** Denotes highly significant

All the coefficients in Table 9, with the exception of those for kernels per head with plant height, and with straw strength, were statistically significant.

The coefficient for tillers per plant with plant height was .48, indicating that these characters are associated in this cross. The number of tillers per plant was an important factor in the calculation of yield. As a result, the correlation coefficient for these characters was high. The number of kernels per head is an important component of yield, especially where the parents differ so greatly in this character, and a coefficient of .34 is evidence for this relationship. Plant height is one of the factors used to compute the cLr as a measure of straw-strength. Therefore, a negative correlation between plant height and straw-strength is inherent in the method of computation.

The coefficients for tillers per plant with kernels per head, and with straw strength, are numerically so low that little association exists between them. Similarly, no association exists between yield with plant height, and yield with straw-strength.

X^2 Tests for Independence

Contingency tables for several combinations of the characters measured in the F_2 generation in this study are presented in Appendix Tables 1 to 9. The results are summarized in Table 14, where the X^2 values are given.

Examination of Appendix Table 1, reveals the association of six-row head type with greater number of kernels per head. There are no six-row type heads with fewer than 42 kernels, and no two-row type heads with more than 38 kernels.

The distribution of head type with kernels per head in Appendix Table 2 does not follow any recognizable trend, and no explanation for a X^2 value with so low a probability is evident.

For head type with plant height (Appendix Table 3), the node for the six-row type plants is two classes below that for plants of the two-row type. This suggests that shorter plants are associated with the six-row head type.

Straw-strength (cLr) appears to be associated with the six-row head type (Appendix Table 4). The mode for the two-row type plants is one class below that of the six-row types.

The distributions for straw-strength with tillers per plant (Appendix Table 5), with plant height (Appendix Table 6), with yield (Appendix Table 7), with kernels per head (Appendix Table 8) and for plant height with tillers per plant (Appendix Table 9) are difficult to interpret, because no recognizable trend is evident to explain X^2 values with such low probabilities.

The correlation studies did not indicate a high degree of association between straw-strength (cLr) and any of the other characters measured. However, the X^2 values calculated, had very low probabilities, indicating a non-random grouping of individuals at certain frequencies. This suggests that a breeder could expect to observe a reasonably high frequency of desired as well as undesired combinations of characters in this population.

Table 10. SUMMARY OF X^2 TEST FOR INDEPENDENCE.

Pairings	X^2 Values	d.f.	P
Head type and tillers per plant	64.39	38	less than 0.005
Head type and kernels per head	3990.84	58	less than 0.005
Head type and plant height	292.97	38	less than 0.005
Head type and straw strength	41.23	32	less than 0.10
Straw strength and tillers per plant	202.06	182	less than 0.005
Straw strength and plant height	524.44	247	less than 0.005
Straw strength and yield per plant	153.79	108	less than 0.005
Straw strength and kernels per head	869.20	392	less than 0.005
Plant height and tillers per plant	2265.90	266	less than 0.005

DISCUSSION

The genetic analysis of quantitative characters is complicated by the lack of discrete differences in the progeny. Accordingly, means, variances and covariances must be used to interpret data from populations exhibiting continuous variation. These statistics give estimates of numerical attributes of the genotype-environment complex that influence breeding results, and provide a basis for making choices during a selection program.

Progress in breeding and selection programs depends partly on the degree of genetic variability present in the population, and the magnitude of the masking effect of the environment on the genetic variation. If a character in a population has great genetic variability, the heritability of that character will be high, and the genotype of the population can be changed readily through selection. In contrast, if there is little genetic variation, where the entire population is homozygous for a character, then the heritability for that character is also high, perhaps 100 per cent. However, since there is no genetic variation, little progress can be made by selection.

All characters in barley, as in other crops are conditioned by genetic factors. In addition, the phenotypic expression of the genotype is affected by the environment. Since all observations and measurements made in a population are made on the phenotype, it is necessary to try to determine how much of the observed variation is genetic in origin, and how much is caused by the environment.

Yield is the final expression of the genetic potential of the plant as influenced by the environment. It is the general vigor of the plant as expressed in number of heads per plant, number of kernels per head, and weight of the kernels. In a breeding program designed to develop improved barley a proper balance of the characters affecting general vigor must be maintained in the selections (31, p. 470). To understand how this balance might be affected, estimates of association between desirable as well as undesirable characters are helpful to a breeder.

In the present study the F_1 plants demonstrated the dominance of the two-row head type in barley. Neatby (46, p. 78), Hayes et al. (32, p. 88-102), Fraser (14, p. 113), and others reported ratios of one six-row type plant to three other type of plants in the F_2 generation of crosses of two-row x six-row barley. All classes of head type ranging from perfect six-row types through head types with varying numbers of lateral florets, to perfect two-row types were observed in these crosses. Similar findings were noted in the F_2 generation of this study, making head type classification difficult.

The importance of tillering to yield in barley, as in other cereal crops, is axiomatic. However, a breeder must not emphasize tillering proficiency at the expense of number of kernels per head, and kernel weight, since these are also components of grain yield. The tillering ability of spaced plants is usually not indicative of the tillering ability of the same plants grown at heavier seeding rates. To study a segregating population, a compromise must be made, and enough space must be left between plants within the row, as well as between the rows, to enable the taking of required measurements and observations. Excessive tillering ability may be detrimental to yield of grain through the wasteful production of culms and heads the plant is unable to mature. It is valuable however, to know the range of tillering ability available before a program to develop greater yield is initiated. This can be determined by extensive plant and row spacing trials but these are difficult to design for a segregating population unless unusually large quantities of seed are available.

In this study, a uniform distance of six inches between plants in the row and 18 inches between rows was used. This spacing provided as uniform an environment as was possible, while allowing room to make required observations and measurements on single plants.

Some degree of dominance for fewer tillers was noted, although part of the genetic variance appeared to be additive. The heritability estimate for tillering was low, indicating that most of the observed variation was environmental in origin. This is in agreement with work reported by Fiuzat et al. (13, p. 417). If the environmental variation was reduced, the heritability estimate would be increased, giving a better indication of results which could be expected from a breeding program. It is postulated therefore that progress in breeding for tiller number in barley should be successful because of the additive nature of the genetic variance.

The environmental effect on the number of nodes per head was not large. Consequently a high heritability estimate was found for number of kernels per head, suggesting that a breeder could make rapid progress when selecting for this character in barley.

Plant height is considerably influenced by environmental variations, and is closely related to the standing ability of barley. It seems reasonable that longer strawed plants would be more subject to lodging during wet, windy weather than would shorter ones. Selection for shorter straw should meet with success, because in this study the genetic variance appeared to be partly additive. However, adequate lodging resistance is not easy to attain through selecting for shorter plants, because a physiological limit is soon reached where reduction in grain yield accompanies further reduction in height (48, p. 338). Perhaps it would be best to select for shortness approaching this physiological limit, then to hold height constant while selecting for either stiffer straw, or straw more pliable and resiliant.

Much study has been devoted to the problem of straw strength in cereal crops. The main difficulty a breeder faces is that of developing a simple and accurate method for evaluation of straw strength. Nelson (47, p. 611-612) noted that environmental conditions conducive to lodging do not occur every year. Often when they do occur, it is with such severity that many plants with varying degrees of resistance are lost from the breeding nursery because they are lodged flat and no differences can be discerned. A technique such as that developed by Grafius (23, p. 416) enables the breeder to grow his nursery in a sheltered place to avoid environmental extremes. There, individual plants can be examined accurately for differences in lodging resistance. The cLr method requires no practice period, and several workers can be used to speed up field observations, provided they all have chains of the same weight and length per link.

In this study, the heritability estimate for straw-strength (cLr) in barley was found to be high, indicating progress in selecting for stronger straw should be effective. However, the genetic variance for straw-strength appeared to be largely non-additive. To the cereal breeder, non-additive genetic variance is usually of lesser importance than is additive genetic variance, because specific gene combinations are lost through rearrangements at synapsis, cross-overs, and fertilization. Some part of this specific gene combination may become fixed in a self-fertilizing population as the segregates resulting from a hybridization approach homozygosity. If this happens, the new rearrangement would be of value to a breeder if he can detect it. Since these fortuitous recombinations would appear in single plants until homozygosity was reached, a technique such as Grafius' cLr would be an extremely valuable tool in the isolation of these individuals.

Previous studies on lodging in cereals have often shown disagreement on the factors affecting this character. Many attempts have been made to measure or evaluate lodging resistance. Studies of root habits, internal stem structure, or straw breaking strength are cumbersome, time consuming, or even misleading. The hanging chain method developed by Grafius (23, p. 416), while somewhat time consuming, seems more satisfactory than many of the other methods devised.

Yield of grain is the final criterion of performance in cereal crops. Several workers have studied the heritability of yield in barley (13, p. 417; 17, p. 187), finding heritability estimates ranging approximately from 40 to 60 per cent. Grafius (22, p. 256) in contrast found heritability for yield to be very low, and concluded there were no genes for yield per se, hence yield could have no heritability. The high estimate of heritability determined for yield in this study may have been a result of there being little genetic variation between the parents. In addition the method used to calculate yield per plant may have masked the existing genetic variation. Both of these factors would tend to increase the estimate of heritability.

The associations found between number of tillers, and yield, and between kernels per head and yield, corroborate the findings of previous workers (21, p. 553; 58, p. 551; 17, p. 187). An association was found to exist between straw-strength and shorter plants, and between straw-strength and the six-row type head.

Between straw-strength and the other characters studied, the associations were not meaningful.

Stronger straw was associated with shorter culms, and with the six-row head type only, in this study. In a selection program designed to develop varieties of barley with improved straw-strength, a breeder should choose parents from the shorter strawed, six-row types.

Measurements made on subsequent generations would yield information making possible a more complete study of the problem of the inheritance of straw-strength and its association with other morphological characters.

SUMMARY

A cross was made between two varieties of spring barley. The parents used were Hannchen, a two-row type, and Harlan, a six-row type. These varieties differ in head type, tiller number, kernels per head, plant height, straw strength and yield.

The objective of the experiment was to study the heritabilities and associations among these characters. The results obtained are summarized as follows:

1. Head Type. The F_1 plants demonstrated the dominance of the two-row head type in barley. The lateral florets of the F_1 plants were sterile, although somewhat larger than those of the two-row parent. The F_2 generation segregated into the two parental types, although many plants were intermediate in head type.

2. Tillering. Partial dominance for the lower number of tillers of the six-row parent was indicated, although part of the genetic variance appeared to be additive. The heritability estimate was 13 per cent, indicating that this character is highly influenced by the environment. It was postulated that since part of the genetic variance is additive, under uniform environmental conditions the heritability estimate would be higher, and selection for tiller number in barley should be successful.

3. Kernels per Head. The dominance of the two-row parent for fewer kernels per head was demonstrated by the F_1 plants. The F_2 generation segregated into two groups with widely disparate means. The variability between the plants of each group was

mainly a result of the variation in nodes per head. The heritability estimate of 97 per cent indicates that a breeder would be successful in selecting for number of kernels per head in barley.

4. Plant Height. Overdominance for tallness was exhibited in the F_1 generation. However, part of the genetic variance of the F_2 was probably additive, suggesting that progress could be made in selecting for plant height in barley. The heritability estimate of 40 per cent indicates that plant height in barley is considerably influenced by the environment.

5. Straw Strength. In this cross, the F_2 generation exhibited overdominance for weaker straw. The heritability estimate of 88 per cent indicates that it would be possible to select for straw strength in barley using the method developed by Grafius to identify the stronger strawed segregates.

6. Yield. Although the heritability estimate for yield was 74 per cent in this study, there were no differences in yield between any of the generations. This was probably because there was little genetic variability between the parents.

7. Associations. The following associations between characters were observed: tillers per plant with yield, and with kernels per head; straw strength (cLr) with the six-row head type, and with shorter culms.

Straw strength was probably associated with tillers per plant, with plant height, with yield, and with kernels per head; and plant height was associated with tillers per plant. However, no discernable trend could be determined from an examination of the contingency tables for these comparisons.

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APPENDIX

Table 1. CONTINGENCY TABLE FOR HEAD TYPE WITH NUMBER OF KERNELS PER HEAD.

Head Type	Number of Kernels Per Head																						
	12	14	16	18	20	22	24	26	28	30	32	34	36	38	42	44	48	52	54	56	60	64	66
2-Row	1	4	12	22	54	90	197	247	304	261	147	74	29	8	0	0	0	0	0	0	0	0	0
Int.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	15	16	0	12	9	8	0
6-Row	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	30	0	43	0	78	0	125
Totals	1	4	12	22	54	90	197	247	304	261	147	74	29	8	8	11	45	16	43	12	87	8	125

Table 1 (continued)

Head Type	Number of Kernels Per Head							
	72	78	84	90	96	102	108	Totals
2-Row	0	0	0	0	0	0	0	1450
Int.	1	0	0	0	0	0	0	72
6-Row	135	161	108	42	17	6	2	755
Totals	136	161	108	42	17	6	2	2277

$\Sigma X^2 = 3990.84 \quad P < 0.005$

Table 2. CONTINGENCY TABLE FOR HEAD TYPE WITH TILLERS PER PLANT.

Head	Class Centers for Number of Tillers Per Plant																	
Type	2	5	8	11	14	17	20	23	26	29	32	35	38	41	44	47	50	Total
2-Row	57	210	341	371	271	204	160	122	66	38	19	8	7	2	0	2	1	1879
Int.	8	25	35	26	26	16	9	10	2	2	0	1	0	1	0	0	0	161
6-Row	36	135	214	228	166	96	69	30	18	9	3	2	0	0	0	0	0	996
Total	101	370	590	625	463	316	238	162	86	49	22	11	7	3	0	2	1	3036

$\Sigma X^2 = 64.39 \quad P < 0.005.$

Table 3. CONTINGENCY TABLE FOR HEAD TYPE WITH PLANT HEIGHT.

Head	Class Centers for Plant Height (cm.)																				
Type	38	41	44	47	50	53	56	59	62	65	68	71	74	77	80	83	86	89	92	95	Total
2-Row	2	6	8	14	18	36	57	102	104	187	190	249	225	209	179	138	73	50	23	13	1883
Int.	0	0	0	0	2	1	9	5	14	21	12	22	16	10	14	9	7	5	0	0	147
6-Row	2	4	14	14	30	50	82	114	112	126	107	108	86	48	44	25	21	8	6	5	1006
Totals	4	10	22	28	50	87	148	221	230	334	309	379	327	267	237	172	101	63	29	18	3036

$\sum X^2 = 292.97$ $P < 0.005$.

Table 4. CONTINGENCY TABLE FOR HEAD TYPE WITH STRAW STRENGTH (cLr)

Head	Class Centers for Coefficients of Lodging Resistance									
Type	0.35	0.55	0.75	0.95	1.15	1.35	1.55	1.75	1.95	2.15
2-Row	5	39	137	134	81	42	56	25	20	10
Int.	0	2	7	14	8	7	1	1	2	0
6-Row	0	18	55	84	47	25	16	24	15	10
Totals	5	59	199	232	136	74	73	50	37	20

Table 4 (continued)

Head	Class Centers for Coefficients of Lodging Resistance							
Type	2.35	2.55	2.75	2.95	3.15	3.35	3.55	Totals
2-Row	10	6	2	3	0	0	0	570
Int.	1	0	0	0	0	0	0	43
6-Row	6	2	0	0	1	0	2	305
Totals	17	8	2	3	1	0	2	918

$\sum X^2 = 41.23$ P is between 0.10 and 0.05.

Table 5. CONTINGENCY TABLE FOR TILLERS PER PLANT WITH STRAW STRENGTH (cLr)

Tillers Per Plant	Straw Strength (cLr), Class Centers									
	0.35	0.55	0.75	0.95	1.15	1.35	1.55	1.75	1.95	2.15
1-3	0	3	8	13	9	0	3	4	1	1
-6	0	11	24	37	25	13	11	4	8	4
-9	1	11	42	61	27	19	10	11	8	7
-12	1	11	61	63	28	14	13	12	6	5
-15	0	14	37	38	21	12	11	12	8	5
-18	0	7	29	34	16	4	11	3	4	0
-21	1	7	18	15	12	8	9	1	1	1
-24	0	1	7	13	7	5	4	4	6	0
-27	0	4	6	3	8	3	5	2	2	1
-30	1	1	1	3	0	3	0	1	0	0
-33	1	2	3	0	1	0	1	0	0	0
-36	0	0	1	1	0	0	1	0	0	0
-39	0	0	1	1	0	0	0	0	0	0
-42	0	0	0	1	0	0	1	0	0	0
Totals	5	72	238	273	154	81	79	54	44	24

Table 5 (continued)

Tillers Per Plant	Straw Strength (cLr), Class Ceneters							
	2.35	2.55	2.75	2.95	3.15	3.35	3.55	Totals
1-3	0	1	0	1	0	0	0	44
-6	7	1	1	1	0	0	0	147
-9	5	3	0	1	0	0	0	196
-12	1	3	0	3	0	0	1	222
-15	3	0	0	0	0	0	1	162
-18	1	0	0	0	0	0	0	108
-21	0	0	0	1	0	0	0	74
-24	0	0	0	0	0	0	0	47
-27	1	0	0	0	0	0	0	35
-30	0	1	0	1	0	0	0	12
-33	0	0	0	0	0	0	0	8
-36	0	0	0	0	0	0	0	3
-39	0	0	0	0	0	0	0	2
-42	0	0	0	0	0	0	0	2
Totals	18	9	1	8	0	0	2	1062

$\Sigma X^2 = 202.06$

$P < 0.005$

Table 6. CONTINGENCY TABLE FOR PLANT HEIGHT WITH STRAW STRENGTH.

Straw Strength Coeffs.	Class Ceneters for Plant Height (cm.)																			
	38	41	44	47	50	53	56	59	62	65	68	71	74	77	80	83	86	89	92	95	Totals
0.3-0.4	0	0	0	0	0	0	0	0	0	1	1	0	0	1	1	0	0	0	0	1	5
0.5-0.6	0	1	0	0	0	3	2	3	3	10	3	10	9	7	7	9	5	0	0	0	72
0.7-0.8	0	0	1	0	2	5	8	16	15	19	25	40	30	2	24	14	8	2	4	1	216
0.9-1.0	0	0	2	1	6	7	11	20	26	29	31	39	31	21	18	12	6	4	1	2	272
1.1-1.2	0	0	3	4	5	4	11	14	13	28	16	15	8	7	8	4	2	4	0	1	150
1.3-1.4	0	0	0	1	3	2	9	8	6	8	7	6	5	9	9	7	1	1	1	0	83
1.5-1.6	0	1	2	0	1	3	1	6	7	8	9	8	11	7	7	4	1	3	1	1	81
1.7-1.8	0	1	0	1	0	2	7	4	9	9	8	6	4	0	2	2	0	0	0	0	55
1.9-2.0	0	1	1	1	2	2	7	6	3	11	1	2	3	1	2	2	0	0	1	0	46
2.1-2.2	1	0	2	1	1	5	2	1	3	2	5	1	0	0	0	0	0	0	0	0	24
2.3-2.4	0	0	2	1	0	2	2	1	3	4	2	1	0	1	1	0	0	0	0	0	19
2.5-2.6	0	0	1	0	0	2	2	2	0	0	0	0	0	0	0	0	1	0	0	0	8
2.7-2.8	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
2.9-3.0	1	0	0	0	0	0	0	1	2	3	1	0	0	0	0	0	0	0	0	0	8
Totals	2	4	14	11	20	40	62	81	90	132	114	128	101	56	79	54	24	14	8	6	1040

$\Sigma X^2 = 524.44$ $\quad P < 0.005$

Table 7. CONTINGENCY TABLE FOR YIELD PER PLANT IN GRAMS WITH STRAW STRENGTH (cLr).

Straw Strength Coeff.	Yield (Grams Per Plant)												Totals
	5	10	15	20	25	30	35	40	45	50	55	60	
0.3-0.4	0	0	2	3	0	0	2	2	0	0	0	0	9
0.5-0.6	8	26	8	9	9	6	3	2	0	0	0	0	71
0.7-0.8	15	62	69	40	22	16	4	2	2	0	0	0	232
0.9-1.0	28	81	56	46	18	10	3	2	2	0	0	2	248
1.1-1.2	18	38	33	30	14	10	3	0	0	0	0	0	146
1.3-1.4	8	22	24	12	8	9	2	0	0	0	0	0	85
1.5-1.6	8	22	22	9	10	3	0	3	0	0	0	0	78
1.7-1.8	8	14	15	9	3	2	0	2	2	0	0	0	55
1.9-2.0	3	16	9	4	9	3	0	0	0	0	0	0	44
2.1-2.2	3	6	6	4	2	2	0	0	0	0	0	0	23
2.3-2.4	6	6	6	2	2	2	0	0	0	0	0	0	24
2.5-2.6	2	2	2	0	0	0	0	0	0	0	0	0	6
2.7-2.8	0	2	2	0	0	0	0	0	0	0	0	0	4
Totals	108	297	254	170	97	63	17	13	6	0	0	2	1027

$\Sigma X^2 = 153.79 \quad P < 0.005$

Table 8. CONTINGENCY TABLE FOR STRAW STRENGTH WITH KERNELS PER HEAD.

Kernels per Head	Straw Strength														
	0.35	0.55	0.77	0.95	1.15	1.35	1.55	1.75	1.95	2.15	2.33	2.55	2.75	2.95	3.15	Total
12	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	2
14	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	2
16	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	2
18	0	0	0	0	0	0	2	0	2	0	0	0	0	0	0	4
20	0	0	12	4	6	2	2	2	4	2	0	0	0	0	0	34
22	0	2	6	10	2	0	0	0	2	2	0	0	0	0	0	24
24	1	4	10	12	14	4	9	2	0	4	2	0	0	0	0	62
26	0	2	24	15	8	10	7	0	2	0	4	0	2	0	0	74
28	2	4	18	12	21	6	8	2	4	0	2	1	0	0	0	80
30	0	2	22	15	13	6	6	0	2	0	2	2	0	0	0	70
32	2	4	12	2	10	3	8	0	4	0	0	0	0	0	0	45
34	0	0	2	9	6	8	0	4	2	0	2	2	0	0	0	35
36	0	2	2	3	1	0	0	2	0	0	0	0	0	0	0	10
38	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2
42	0	0	2	2	2	0	0	0	0	2	0	0	0	0	0	8
44	0	0	2	0	2	0	0	0	0	0	0	0	0	0	0	4
48	0	0	0	8	4	6	0	2	2	0	0	0	0	0	0	22
52	0	0	0	2	0	2	0	0	0	0	0	0	0	0	0	4
54	0	0	4	6	0	2	0	0	0	0	0	0	0	0	0	12
56	0	0	6	2	0	0	0	0	0	0	0	0	0	0	0	8
60	0	4	0	10	4	4	4	2	0	0	2	1	0	0	0	31
64	0	0	0	2	14	4	2	0	0	0	2	0	0	0	0	24
66	0	4	6	10	4	8	0	2	2	2	0	0	0	0	0	38
74	0	0	6	6	2	3	0	2	0	4	2	0	0	0	1	26
78	0	2	6	4	2	2	0	6	2	2	0	0	0	2	0	28

Table 8 (continued)

Kernels Per Head	Straw Strength														
	0.35	0.55	0.77	0.95	1.15	1.35	1.55	1.75	1.95	2.15	2.33	2.55	2.75	2.95	3.15	Total
84	0	2	2	7	2	1	2	2	2	0	0	0	0	0	0	20
90	0	0	2	4	2	0	4	0	2	0	0	0	0	0	0	14
96	0	0	0	4	0	0	2	0	0	0	0	0	0	0	0	6
102	0	2	4	0	0	0	0	0	0	0	0	0	0	0	0	6
Totals	5	34	152	149	121	71	56	28	34	18	18	6	2	2	1	697

$\Sigma X^2 = 869.20 \qquad P < 0.005$

Table 9. CONTINGENCY TABLE FOR PLANT HEIGHT (CMS.) WITH TILLERS PER PLANT.

Tillers Per Plant	Class Centers for Plant Height (Cm.)																				
	38	41	44	47	50	53	56	59	62	65	68	71	74	77	80	83	86	89	92	95	Total
1-3	11	7	10	5	3	10	14	6	12	9	7	0	1	0	6	0	0	0	0	0	101
4-6	6	3	9	15	22	29	36	42	40	57	26	43	41	6	3	12	6	0	0	0	392
7-9	0	0	0	3	19	27	57	67	61	103	51	71	85	41	13	22	6	3	2	0	638
10-12	0	0	0	0	3	14	20	66	48	98	89	78	55	50	42	28	15	6	1	0	613
13-15	1	0	3	0	6	1	21	24	31	49	40	76	64	64	35	23	6	24	3	1	472
16-18	0	0	0	0	3	0	3	12	16	18	27	59	57	28	28	20	27	7	6	3	314
19-21	1	0	0	0	0	0	0	6	3	23	6	35	29	26	55	9	13	5	4	3	218
22-24	0	0	0	0	0	0	0	6	3	13	0	9	25	23	22	23	11	8	0	4	140
25-27	0	0	0	0	0	0	0	0	4	6	6	5	12	10	0	5	11	8	0	0	61
28-30	0	0	0	0	0	0	0	0	0	0	7	1	15	4	0	9	0	0	1	3	40
31-33	0	0	0	0	0	0	0	0	0	0	3	3	1	3	2	0	6	0	0	3	21
34-36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	3
37-39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	3	3	0	10
40-42	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	4
43-45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
46-48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	3
Totals	19	10	22	23	56	81	148	223	228	376	262	380	389	255	206	158	96	67	20	17	3036

$\Sigma X^2 = 2265.90 \qquad P < 0.005$