THE EFFECT OF LEAF RUST ON THE COMPONENTS OF YIELD AND OTHER CHARACTERISTICS OF HARD RED WINTER WHEAT

by

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INTRODUCTION

Leaf rust of wheat, Puccinia recondita Rob. ex Desm., is considered to cause substantial reductions in grain yield in certain years. Pady et al., (1955) estimated that the annual reduction of wheat production in Kansas in the period of 1938 through 1952 inclusive was more than 5,413,000 bushels. It has been established that leaf rust can cause major damage under certain environmental circumstances.

The development of varieties of hard red winter wheat resistant to the prevalent physiologic races of leaf rust has been a major objective of the wheat breeding programs in the hard red winter wheat area of the great plains. Wheat varieties resistant to leaf rust are considered as an added increase in dollars or bushel production over the standard susceptible varieties. However, satisfactory experimental field methods capable of evaluating the effect of leaf rust on wheat have not been adequately tested. The problem involves the estimation of severity of the disease and translation to an accurate loss figure. Some plant diseases are spectacular but inflict relatively little economic damage, others subtly destroy a significant portion of the crop. The loss from a disease which may be disregarded, economically, varies with diseases. Therefore, the apparent importance of a problem may be far from its true relative importance. Problems appear to be important when they are well publicized or when they frequently come to the attention of the researcher or administrator.

Accurate loss information is essential for the proper evaluation of a disease control measure. The question arises as to whether the leaf rust problem is serious enough to justify expensive attempts to produce resistant varieties at the expense of other important work. Leaf rust damage has been estimated on the basis of limited knowledge of the leaf rust-wheat relationship. These estimates have been subjective and contingent upon the experience of the estimator. Chester (1946) stated that distorted conclusions of leaf rust damage have been drawn due to a lack of a method of measuring leaf rust damage.

A sound experimental procedure conducted under natural field conditions, using procedures which will give an estimate with a high level of confidence, is needed to properly evaluate the effects of the leaf rust pathogen. Such a method must be capable of accurately detecting yield differences among strains of wheat differing in their ability to resist the pathogen.

This study was a continuation of work begun by Bieber (1960). The object of the study was to estimate damage produced by the leaf rust organism, *Puccinia recondita* Rob. ex. Desm., using resistant and susceptible sister lines of hard red winter wheat. An effort was made to determine what, if any, effect resistant wheats have in increasing yield under environmental conditions typical of Kansas. Prior to the study by Bieber (1960), no published research had been conducted in America using nearly isogenic lines differing in rust response as a method of evaluation. As in Bieber's work, an objective was to continue evaluation of this method.

Apart from a purely scientific interest, a method to obtain an accurate determination of the damage caused by leaf rust offers the only reliable guide in a rational policy of control. This study attempts to evaluate a method and use that method to estimate the effects of leaf rust on hard red winter wheat strains varying in resistance.

REVIEW OF LITERATURE

In a preliminary study, Bieber (1960) presented a comprehensive review of the literature pertaining to the studies of the effect of leaf rust on the yield of hard red winter wheat. The objective of this review was to supplement and briefly summarize Bieber's presentation.

Carleton (1899) stated that orange leaf rust, as a rule, does very little damage even when it is abundant. He concluded that only occasionally under certain conditions and in certain localities did considerable damage arise if the rust occurred much in advance of harvest. During 1917, Melchers (1917) observed abundant leaf rust on the wheat crop in Kansas. Careful observation indicated that no other factors could be responsible for the poor quality and low yields. Melchers estimated that one field was reduced 38 percent.

Wood and Nance (1938) reported that in areas where leaf rust is most important it occurs every year to a greater or lesser extent with the result that its effect on yield is apt to be overlooked except in epidemic outbreaks. They noted that in contrast to the suddenness of outbreaks of stem rust, leaf rust is likely to appear early and develop steadily throughout the season. This contrast with stem rust was considered responsible for minimizing leaf rust damage estimates.

Chester (1950) stated that prior to 1926 losses from wheat leaf rust were generally regarded as negligible or even beneficial to wheat.

The work of several researchers in the period, 1926 through 1936, determined that leaf rust can cause damage to the wheat plant. In greenhouse experiments, Mains (1930), Johnston and Miller (1934), and Johnston (1931) found that lowered yields were due primarily to fewer kernels per spike when infection was early, a pre-blossom damage, and reduced kernel weight when later infection occurred, a post-blossom damage. The physiological effects on the wheat plant were considered to be an increase in transpirational water loss and premature death of leaves which are essential in the production of carbohydrate.

In a greenhouse study to determine the effect of two temperatures associated with leaf rust infections, Waldron (1936) found that plumpness of the kernel was retained at the expense of size. Almost no shriveling of the grain was observed. He concluded that if the plant becomes infected early in the stages of its life, injury is due mainly to the formation of fewer and smaller kernels. Waldron found that if leaf rust is delayed until after the flowering stage the damage is largely confined to reduced kernel size. Waldron also found that the yield of selections susceptible to flecking was reduced 15 percent from the check grown in the absence of leaf rust.

In a field experiment, Caldwell _et al._, (1934) compared seven varieties varying in reaction from extremely susceptible to highly resistant. In most varieties yield reductions were proportional to rust severity. However, the variety Fulhard was not reduced in yield even though it was severely rusted. The authors stated that severe infections were reached soon after flowering and that three-fourths of the grain loss was due to a reduction in number of kernels per spike and the remainder due to a reduction in weight per kernel. Even under maximum leaf rust infection, no shriveling of the grain occurred.

In field studies, Samborski and Peterson (1960) found that leaf rust initiated at an early stage of development reduced yield, 1000-kernel weight, and bushel weight of one susceptible and three resistant varieties of wheat. The yield loss of the susceptible was 58 percent when compared to the rust free check. Yield loss on the resistant varieties ranged from 12 to 28 percent. Losses on resistant varieties were attributed to flecking of the leaves. Density of inoculum and amount of necrosis were directly related to the amount of loss on the resistant, but not immune, varieties. The extent of damage to the resistant varieties depended on the type of resistance involved since the amount of necrosis resulting from each infection determined the rate of leaf destruction. Their results pointed out that yield tests with resistant varieties will be influenced by the proximity of susceptible plants that can provide a heavy source of inoculum. Therefore, the great advantage of the resistant variety may be nullified in a yield comparison.

Suneson (1954) used isogenic lines of the variety Baart differing in resistance to stem rust to evaluate damage under epidemic conditions. He stated that the effect of stem rust on the yield of wheat was confounded by genetic, pathologic, and environmental factors. He concluded that stem rust may be less damaging than is commonly thought and a high type of resistance may not be necessary for practical purposes. In his studies, the yield of susceptible Baart was reduced 25-47 percent, whereas, the yield of a moderately resistant line was reduced 6-20 percent. Suneson suggested that a near immune reaction to the disease may not be necessary in a commercial wheat as a moderately resistant variety grown on large acreages has been sufficient to check epidemics in California.

The results of the preliminary investigation of the effects of leaf rust and stem rust of wheat under field conditions are reported by Bieber (1960). Yield, test weight, and 500-kernel weight differences between resistant and susceptible pairs were statistically evaluated using t-tests for single row data and analysis of variance for replicated plot data. In the study an attempt was made to evaluate the effect of stem rust and leaf rust using sister lines of a Pawnee-type wheat. Results indicated that test weight and kernel weight were significantly affected by leaf rust reaction. Yield data were inconclusive but indicated that an effect upon yield could be detected by this method. Bieber concluded that it appears that sister lines of wheat are adaptable to the evaluation of leaf rust and stem rust damage; however, further study will be needed before comparisons can be made between this and other methods of disease damage evaluation.

The environment during the development of the wheat crop is a major factor in determining the amount of damage. Johnston (1938) summarized the conditions leading to the heavy leaf rust losses incurred in 1938. He found that heavy infections were late in their development in 1937 when a loss of 0.4 percent was reported but were very early in 1938 when a loss of 12 percent was reported.

Chester (1946) described the environmental conditions associated with heavy infection. He suggested that abundant rainfall, heavy dews, and early warm weather accompanied by early spore showers favor damaging leaf rust infections.

Chester (1944 and 1950) made a thorough search of the available literature for methods of measuring and calculating plant disease losses. He explored all aspects of obtaining and utilizing estimates, analyzed the standards on which estimates were based, and pointed out errors of concept and practice. He defined plant disease loss appraisal as an important field in its own right in opposition to the usual notion of loss estimates as subordinate to other phases of plant disease research. Chester (1950) stated that no one method of evaluation is entirely free of error. Chester (1944) stated that an ideal method of appraisal must compare yields, under rust attack, of host strains that are genetically similar, but differ in rust susceptibility and be conducted on a scale that permits statistical analysis.

In regard to plant disease forecasting, Miller (1958) stated that there is a need for a more complete understanding of the relation between the disease and the environment. For the same disease, criteria that are successful in disease evaluation in one area may not be useful in another with a different climatic environment.

The use of sulphur for the prevention of leaf rust infection is widely accepted. Forsyth and Peterson (1958) stated that economical control of stem rust and leaf rust of wheat can be obtained with the best protective type of fungicides if the weather conditions do not become adverse during the application program. No fungicide was successful in their study in 1953 due to frequent showers. In a study using sulphur as a preventive fungicide, Greaney (1934a) found that in the absence of rust and other leaf and stem diseases, the dusting of wheat varieties with sulphur during the growing period had no appreciable effect on yield. However, in a similar study, Greaney (1934b) found that the stem rust schedule of sulphur dusting also controlled wheat scab, black chaff, "smudge", and minor leaf diseases. Scab was reduced from an infection of 80 percent to 13 percent in one test. He concluded that the total effect of sulphur dusting on incidental diseases, in addition to rust, should be included in the economical evaluation of this control method.

MATERIALS AND METHODS

The resistant and susceptible lines employed in this study were selected from the progeny of a Sinvalocho-Pawnee[2] x Mediterranean-Hope-Pawnee[3] cross (X 52V) made in 1952. Table 1, page 9, presents the history of each selection used in the s tudy. Each line was entered in order of its 1959 selection number. The same

Table 1. Entry and selection numbers in the leaf rust study for the years 1957 through 1961.

Family	1957 Entry No. F_5	1958 Entry No. F_6	1959 Entry No. F_7	1960 Selection & Entry No., F_8	1961 Entry No. F_9	1961 Sel. No. F_9	Rust Response Leaf Rust	Rust Response Stem Rust
10297	11580	353	901	59901	474	59901	S	MR
	11581	354	902	59902	473	59902	R	MR
10313	11747	371	911	59911	468	59911	S	SR
	11748	372	912	59912	467	59912	R	SR
10294	11548	R2614	925	59925	472	59925	S	S
	11551	R2617	926	59926	471	59926	R	R
10295	11554	R2620	927	59927	470	59927	R	MR
	11561	R2627	928	59928	469	59928	S	MR
10298	11592	R2658	935	59935	463	59935	R	MR
	11597	R2663	936	59936	464	59936	S	MR
10310	11711	R2777	959	59959	466	59959	R	MR
	11712	R2778	960	59960	465	59960	S	MR
10313	11738	R2804	965	59965	461	59965	R	MR
	11743	R2809	966	59966	462	59966	S	MR

order was followed in reporting the data gathered in this study. Records prior to 1957 were lost in a 1957 fire which destroyed the small grain breeding offices.

Each family originated from the progeny of an F_2 plant that was heterozygous for leaf rust response. In this study a family was represented by a resistant and a susceptible line which formed a pair nearly isogenic but differing in response to leaf rust.

Leaf rust resistant F_2 plants were harvested in 1954 and the progeny from each was grown in a three foot row at the North Agronomy Farm in 1955. The F_3 rows which were segregating for leaf rust reaction were harvested. The non-segregating rows were discarded. Each segregating row harvested was the progeny of a heterozygous F_2 plant. Seed from each of these segregating F_3 rows was replanted in 1956 as a three foot row. In 1956, random spike selections were harvested from the F_4 rows which were clearly segregating for response to leaf rust. Each spike selection was grown as a three foot row in 1957. These F_5 row numbers are included in table 1. At harvest, non-segregating resistant and susceptible lines were selected and harvested. Segregating lines were discarded. There were 323 resistant and susceptible lines, representing 29 families, selected. In 1958, the 323 lines were grown at the Ashland Agronomy Farm as eight foot single rows. The F_6 lines grown at Ashland are presented in table 1 with an "R2" code preceding the 1958 entry number used at the North Agronomy Farm. There was sufficient seed of 40 of the 323 lines to plant two, eight foot, rows of each at the North Agronomy Farm. From this material grown in 1958, pairs consisting of a resistant and a susceptible line were selected to be grown as paired, eight foot, single rows in 1959. Two pairs used in this study were selected from the two row plots and five pairs were selected from the single rows at Ashland. Pairs were selected on the basis of the 1958 rust readings. The resistant member of each pair represented the highest level of leaf rust resistance present in the family and the susceptible member the lowest. Selection numbers were assigned to the paired lines grown in 1959. Sufficient seed was harvested from the F_7 paired single rows to plant replicated comparisons in 1960. Seven pairs were selected from the material grown in 1959. Each pair consisted of a resistant and a susceptible line homogeneous for leaf rust response. The seven pairs represented six F_2 families. Two pairs originated from family 10313. Each of the members of a pair was similar in its response to stem rust except for family 10294. Selection 59925 was susceptible and selection 59926 was resistant to stem rust.

This study was planned to determine the effects of three treatments on the yield components and other characteristics of sister lines of wheat differing in response to leaf rust. The three treatments were application of dusting sulphur, artificial leaf rust infection, and natural leaf rust infection. Each treatment was to be grown as a thrice replicated experiment in 1960 and 1961. The experiment to compare the performance of the resistant and susceptible lines, using a sulphur treatment to prevent leaf rust infection, was planted at the North Agronomy Farm.

The second experiment consisted of artificially inoculating leaf rust susceptible spreader rows planted in the study to insure a source of leaf rust inoculum. It was also planted at the North Agronomy Farm. The third experiment to study the effects of natural infection was planted at the Hutchinson Experimental Field.

Each experiment was planted in the same manner in 1960 and 1961. The sulphur experiment was grown as replications I-III, the artificial infection experiment was grown as replications IV-VI, and the natural infection experiment was grown as replications VII-IX. Each of the experiments, consisting of three replications of the seven leaf rust pairs, was planted in a split-plot design. Each pair formed a main plot. The two levels of resistance formed the subplots. Each subplot consisted of four rows, 11.6 feet long, spaced twelve inches apart. The seeding rate was 83 pounds per acre at Manhattan and 75 pounds per acre at Hutchinson. The subplots were arranged end to end. The pairs were randomized within each replication and the resistant and susceptible line assigned at random within each main plot. This was done by assigning a number to each of the 14 selections and placement of the second member of the pair with the randomly selected first member.

The spreader rows in the artificial infection experiment were planted in the alleys perpendicular to the rows in the study. Each subplot was bounded at both ends by a spreader row.

The natural infection experiment was planted at Hutchinson

October 20, 1959. The sulphur and artificial infection experiments were planted at the North Agronomy Farm October 14 and October 22, 1959, respectively. In the fall of 1960, the Hutchinson experiment was planted October 6 and the two Manhattan experiments October 11.

Winter damage ratings were recorded April 18, 1960, for the two experiments grown at Manhattan. A scale of 0-10 was used. A zero rating indicated no living plants and a ten rating represented the stand and vigor expected under normal conditions.

The 1960 experiments were not conducted as planned, because each of the three plantings was subjected to natural leaf rust infection. In 1961 each experiment was conducted as planned. Twenty applications of commercial dusting sulphur were applied to the sulphur experiment at approximately sixty pounds per acre. The first dusting was applied April 25 to plants in the pre-boot stage. Dust was applied after each rain to insure constant protection. Dusting continued until harvest. Spores of a composite of physiologic races of leaf rust were inoculated by needle into spreader rows in the artificial infection experiment on April 14, April 22, and May 2.

Leaf rust readings were taken on all three experiments in 1960 and on the two Manhattan experiments in 1961. Percent leaf rust infection was estimated using the modified Cobb scale, Peterson et al., (1948). Stem rust response was recorded on all three experiments in 1960 and on the natural infection at Hutchinson and artificial infection at Manhattan in 1961. No stem rust percentage readings were recorded.

Date of half bloom and height at maturity notes were recorded for each of the three experiments in 1961.

The two experiments at Manhattan were harvested and threshed July 5, 1960 and July 10, 1961. The Hutchinson experiment was harvested and threshed June 30, 1960 and July 1, 1961. Nineteen and two-tenths square feet were harvested from the center two rows of each subplot.

Plans were made to appraise four components of yield; yield, test weight, 500-kernel weight, and kernels per spike. Yields, relative test weights, and 500-kernel weights were recorded on each of the three experiments 1960 and 1961. Kernels per spike were recorded on each experiment in 1961. The yield of each subplot was recorded in grams. The yield in grams per subplot may be converted to pounds per acre by multiplying the subplot yield in grams by a factor of five. Relative test weights were determined by weighing a standard sample of grain in a flat bottomed brass cylinder. The inside dimensions of the cylinder were 2.3 cm in diameter and 7.1 cm in height. Relative test weights and 500-kernel weights were recorded to .01 accuracy. The number of kernels per spike measurement was obtained by averaging the number of kernels from three spikes which were randomly selected from the center two rows of each subplot. Spikes were selected, boxed, and threshed individually in the laboratory.

Each yield component measured from each of the experiments was analyzed singly using an analysis of variance (Snedecor, 1956). It was assumed at the outset of the study that all observations would be independent, random, and normally distributed. The appropriate mathematical model for each experiment is described by the formula:

$$Y_{ijk} = U + R_i + F_j + \alpha_{ij} + S_k + (FS)_{jk} + E_{ijk}$$

where Y_{ijk} is the performance of an individual subplot, U is the grand mean of all subplots, R_i is the added variability beyond α_{ij} due to replication, F_j is the added variability beyond α_{ij} due to family differences, α_{ij} is error a, the random experimental error associated with the main plots, S_k is the fixed added effects beyond the interaction of families x resistance which is due to resistance, $(FS)_{jk}$ is the effect of the interaction between families and resistance, and E_{ijk} is error b, the random experimental error associated with the subplots. Each family formed a main plot and each line a subplot. The assumption that replications and families were random effects and resistance was a fixed effect was made at the outset of the study. The appropriate analysis of variance for each component of yield took the following form:

Source	d.f.	Expected Mean Square
Main Plots:		
Replications	(r-1)	$\sigma_E^2 + S\sigma_\alpha^2 + SF\sigma_R^2$
Families	(f-1)	$\sigma_E^2 + S\sigma_\alpha^2 + RS\sigma_F^2$
Error a	(r-1)(f-1)	$\sigma_E^2 + S\sigma_\alpha^2$
Subplots:		
Resistance	(s-1)	$\sigma_E^2 + R\sigma_{FS}^2 + RF\sigma_S^2$
Family x Resistance	(f-1)(s-1)	$\sigma_E^2 + R\sigma_{FS}^2$
Error b	f(r-1)(s-1)	σ_E^2

where r = the number of replications, f = the number of families, and s = the levels of resistance. The main plot analysis was that of randomized blocks with the seven families replicated in three replications. The subplot analysis was the two levels of resistance randomized in each of the twenty-one main plots. The object of the analysis of variance was to detect any significant fixed added effect of the leaf rust on the yield, test weight, 500-kernel weight, and kernels per spike in each of the three experiments. The appropriate error mean square for testing whether resistance significantly affected performance was the interaction (FS) mean square. The random effects of replications and families were appropriately tested using error a as the denominator in the F ratio. Error b was used to test the interaction (FS) for significance.

An analysis of variance combining the 1960 and 1961 data for similar experiments was conducted. The general method used is described by Federer (1955). Before the combined analysis of variance was conducted, a test was performed to determine whether or not the error variances for the experiments being combined could be considered homogeneous. Snedecor's test in which F is calculated as the quotient of the larger variance divided by the smaller was used.

In this study one asterisk (*) denotes an F value which is significant at the 5 percent level of rejection, two asterisks (**) denote a highly significant difference at the 1 percent level, and three asterisks (***) denote a very highly significant difference at the .5 percent level of rejection.

Missing plot data were computed using the technique described by Snedecor (1956).

EXPERIMENTAL RESULTS

The data collected in this study are presented in tabular form in an appendix. The 1960 results are included in tables 1 through 12 and the 1961 results are included in tables 13 through 28. The data for each component of yield are assembled by experiment and presented in a standard form. Tables 3 through 11 include the yields, relative test weights, and the 500-kernel weights recorded for each subplot in the three experiments conducted in 1960. Table 12 includes the complete analysis of variance on each of the three factors for each of the three experiments grown in 1960. Tables 16 through 27 present the raw data for yield, relative test weight, 500-kernel weight, and kernels per spike recorded for each subplot in the three experiments grown in 1961. Table 28 presents the complete analysis of variance on each of the four factors for each of the three experiments grown in 1961.

Table 29 in the appendix presents the analysis of variance of the combined data from replications IV-VI grown at Manhattan in 1960 and 1961. Table 30 presents the analysis of variance on the combined data from replications VII-IX grown at Hutchinson in 1960 and 1961.

The results of the 1960 and 1961 experiments are discussed separately.

1960 Results

The two experiments conducted at Manhattan were damaged by frost early in November of 1959. Table 1 in the appendix summarizes the winter damage readings taken April 18, 1960. All plots were damaged. Thin and irregular stands persisted until early May. Replications IV-VI were planted eight days later than replications I-III. The readings indicate the later planting was not damaged as severely as the earlier planting. The mean of the resistant lines and the mean of the susceptible lines in each experiment were similar. Selections 59925 and 59926 were damaged most severely in both experiments.

The mean leaf rust and stem rust reading for the three replications in each experiment are included for each selection in table 2 of the appendix. Leaf rust infection was late in developing in each of the three experiments. Natural leaf rust infections were initiated at about the flowering stage. On May 30, 1960 at Manhattan, a very light leaf rust infection was noted. Stem rust was developing notably faster and spreading uniformly throughout the wheat nurseries. Infections of stem rust were heaviest in the area where replications I-III were grown due to the close proximity of inoculum from the spreader rows in the botany stem rust evaluation nursery. The leaf rust and stem rust readings were taken at Manhattan on June 15. An extremely heavy stem rust infection in replications I-III made it necessary to record only the response type of the selections. By June 20 the stem rust had reached epidemic form in replications I-III and was killing the plants. At Hutchinson the natural leaf rust infection was light and scattered as late as May 24. It was estimated that the heaviest infection on that date was 5-10 percent. The leaf rust and stem rust readings recorded in table 2 of the appendix were taken June 13.

In view of the heavy stem rust infection in the Manhattan experiments, it was suspected that the differing stem rust response of the two selections representing family 10294 may have provided a bias toward greater differences due to resistance because the member which was susceptible to leaf rust was also susceptible to stem rust. An analysis of variance was conducted for each of the components in each of the three experiments with the data from family 10294 removed. Comparison of the F values with those obtained from analysis of the entire data resulted in leaving the data from family 10294 in the 1960 comparisons.

The 1960 raw data for yield, relative test weight, and 500-kernel weight are presented in tables 3 through 11 in the appendix. The complete analysis of variance for each component is included in table 12 of the appendix. The relative test weight and 500-kernel weight were missing for selection 59936 in replication IV and had to be calculated using the missing plot technique prescribed by Snedecor (1956). The same procedure was used to compute the relative test weight for selection 59926 in replication IV. Discussion of F values for each component for each experiment would involve undue repetition and confusion. The levels of significance associated with the F value computed for each source of variation for each component are presented in a condensed form in table 2, page 20.

Replications were a significant source of variation in only two instances. A highly significant difference among replication means was observed in the yield analysis of replications IV-VI

Table 2. Levels of significance for yield, relative test weight, and 500-kernel weight for sources of variance studied in three experiments in 1960.

Source	Manhattan		Hutchinson
	Rep I-III	Rep IV-VI	Rep VII-IX
	YIELD		
Main Plots:			
Replications	n.s.	**	n.s.
Families	*	***	n.s.
Subplots:			
Resistance	***	*	*
Family x Resistance	n.s.	**	n.s.
	RELATIVE TEST WEIGHT		
Main Plots:			
Replications	n.s.	n.s.	n.s.
Families	n.s.	n.s.	n.s.
Subplots:			
Resistance	***	n.s.	n.s.
Family x Resistance	n.s.	n.s.	*
	500-KERNEL WEIGHT		
Main Plots:			
Replications	***	n.s.	n.s.
Families	***	***	**
Subplots:			
Resistance	***	**	***
Family x Resistance	***	n.s.	**

and in the 500-kernel weight analysis of replications I-III. Family differences were a significant source of yield variation in replication I-III and very highly significant source in replications IV-VI. Significant differences occurred among family means for 500-kernel weight in each of the three experiments. The results indicate that significant differences in performance among pairs may exist.

The mean yield of the resistant lines was significantly greater than the mean yield of susceptible lines in each of the three experiments. Highly significant differences in 500-kernel weight due to the additive effect of resistance were also recorded for each of the three experiments. It is noted that relative test weight means were unaffected by the additive effect of resistance in replications IV-VI and VII-IX. However, a very highly significant F value was associated with resistance in replications I-III.

The highly significant F value for the family x resistance interaction effect on yield for replications IV-VI is due mainly to a reversal of the yield performance of selections 59959 and 59960. The significant interaction effect on relative test weight in the Hutchinson experiment was caused by several susceptible selections outperforming the resistant member of the pair.

Replications, families, resistance, and the family x resistance interaction each gave very highly significant F values in the analysis of 500-kernel weight data from replications I-III.

Conclusions from significances obtained in the analysis of yield component data for 1960 indicate that there was a difference in the mean performance of the resistant and susceptible lines for yield and kernel weight, a difference in the mean performance of the seven families for yield and kernel weight, and an indication that a family x resistance interaction may exist under certain conditions. Significant reductions in test weight were not detected except in the presence of heavy stem rust.

1961 Results

The mean date of half-bloom for each selection is presented for each of the two Manhattan experiments in table 13 of the appendix. The grand means for resistant and for susceptible lines in each experiment were identical. The data indicate that the resistant and susceptible lines were similar in their date of half-bloom.

The height data given in table 14 of the appendix indicates that the means of the resistant and susceptible lines were similar. Examination of the data reveals a three-inch difference in mean height between the resistant and susceptible members of two pairs in the artificial infection experiment. In both pairs, 59925-59926 and 59935-59936, the resistant member was taller.

Leaf rust readings from the two Manhattan experiments are presented in table 15 of the appendix. Leaf rust failed to become established in the sulphur experiment. The plants in the sulphur experiment remained vigorous and free of measurable disease damage until harvest. Cool May weather delayed the development of leaf rust inoculum on the spreader rows in the artificial infection experiment. On May 18 the first infection pustules were noted in the experiment. At that time, reinfection pustules were noted at primary infection sites of the spreader plants. Warm, humid weather prevailed from June 1 through harvest. The leaf rust readings included in table 15 were recorded June 10. The infection increased rapidly thereafter until flag leaves of all susceptible lines in the artificial infection experiment were near 100 percent infected before they became dry. On June 15 the leaf rust infection at Hutchinson had not developed so that readings could be taken. Hot dry winds the last days of June dried the leaves making it impossible to detect the extent of the infection.

The stem rust response of each selection is included in table 15. Stem rust infections were light in the artificial infection and natural infection experiments. Stem rust did not develop in the sulphur experiment.

A very heavy, but variable, infection of speckled leaf blotch, Septoria tritici Rob. ex Desm., was noted in the experiments at Manhattan. Percent of the flag leaf dead on June 11 was estimated at 0-10 percent in the sulphur experiment and 40-60 percent in the artificial infection experiment. No readings were taken on the subplots because the infection was not uniform.

The 1961 subplot data and means for yield, relative test weight, 500-kernel weight, and kernels per spike are presented in table 16 through 27 in the appendix. Table 3, page 24, includes the level of significance of each F value computed for the sources of variance studied in each experiment. For the complete analysis of each experiment see table 28 of the appendix.

The object of the sulphur treatment experiment was to detect yield differences between resistant and susceptible lines that may be due to genetic effects other than leaf rust response. Sulphur dusting controlled the leaf rust. The difference between the mean performance of the resistant and the susceptible lines was not significant for each of the components of yield studied. These results indicated that differences in mean performance of

Table 3. Levels of significance for yield, relative test weight, 500-kernel weight, and kernels per spike for sources of variance studied in three experiments in 1961.

Source	Manhattan		Hutchinson
	Sulphur Rep I-III	Artificial Infection Rep IV-VI	Natural Infection Rep VII-IX
YIELD			
Main Plots:			
Replications	n.s.	n.s.	**
Families	**	n.s.	n.s.
Subplots:			
Resistance	n.s.	**	n.s.
Family x Resistance	n.s.	n.s.	n.s.
RELATIVE TEST WEIGHT			
Main Plots:			
Replications	n.s.	n.s.	n.s.
Families	***	*	n.s.
Subplots:			
Resistance	n.s.	n.s.	*
Family x Resistance	n.s.	n.s.	n.s.
500-KERNEL WEIGHT			
Main Plots:			
Replications	n.s.	n.s.	*
Families	***	n.s.	n.s.
Subplots:			
Resistance	n.s.	**	n.s.
Family x Resistance	***	n.s.	n.s.
KERNELS PER SPIKE			
Main Plots:			
Replications	n.s.	n.s.	n.s.
Families	n.s.	*	n.s.
Subplots:			
Resistance	n.s.	n.s.	n.s.
Family x Resistance	n.s.	n.s.	n.s.

resistant and susceptible lines under leaf rust attack should be a direct result of the disease. The significances associated with the F values computed for families indicates that there were genetic differences in the performance potential of each family for yield, relative test weight, and 500-kernel weight. A very highly significant family x resistance interaction for 500-kernel weight indicated that the resistant and susceptible lines did not compare the same in each family in the absence of leaf rust. A higher kernel weight average for the susceptible line 59901 than the resistant member of the pair, 59902, contributed to this interaction.

The results of the two experiments under leaf rust attack were influenced by the light infection which occurred at Hutchinson and the heavy, but late, infection at Manhattan. Highly significant F values for the resistance source of variation were obtained for yield and relative test weight evaluation of the artificial infection experiment. Families accounted for a significant source of variation in relative test weights and kernels per spike in the same experiment. The lack of significant F values from the Hutchinson data indicates even less damage by the disease. A significant resistance effect did occur for relative test weight at Hutchinson but means in table 25 of the appendix reveal that the susceptible lines outperformed the resistant lines.

A summary of the 1961 results will indicate that lines used in this study differed in performance among families but were similar in performance within families in the absence of leaf rust, the infection at Hutchinson was too light to detect a resistance effect on any of the four components, and under a somewhat heavier artificial infection at Manhattan, leaf rust reduced yield and 500-kernel weight. Significant differences in mean kernels per spike were not detected in 1961.

Combined Experiments

Summarized analysis of the 1960 and 1961 data for yield, relative test weight, and 500-kernel weight taken from replication IV-VI grown at Manhattan in 1960 and 1961 are included in table 29 of the appendix. Data from replications VII-IX grown at Hutchinson in 1960 and 1961 are summarized in table 30 of the appendix for the same three components of yield.

Prior to the analysis of the combined data, homogeneity of variance for each component was checked. F values computed for error a and error b indicated that heterogeneity of variance between years occurred for several of the components measured. The test weights taken at Manhattan were nonhomogeneous for both main plot and subplot values taken in 1960 and 1961. A check of error a and error b associated with the Hutchinson comparisons indicated a significant heterogeneity of variances occurred for error a in the yield analysis. No other significant F values were detected.

Results of a combined analysis, when it is known the error mean square is made up of heterogeneous experimental errors, must be interpreted with caution. Nonhomogeneous experimental error reduces the efficiency of the F value to detect true differences which may exist among means. Conclusions drawn from F values computed from data which are known to differ in experimental error will result in conservative decisions.

A summary of the levels of significance associated with F values obtained from the combined data is presented in table 4.

Table 4. Levels of significance for yield, relative test weight, and 500-kernel weight for sources of variance studied using combined data from similar experiments in 1960 and 1961.

Source	Manhattan Rep IV-VI	Hutchinson Rep VII-IX
	YIELD	
Main Plots:		
Years	***	***
Replications	n.s.	***
Families	***	***
Subplots:		
Resistance	**	***
Resistance x Year	n.s.	*
Family x Resistance	n.s.	n.s.
	RELATIVE TEST WEIGHT	
Main Plots:		
Years	n.s.	***
Replications	n.s.	n.s.
Families	n.s.	n.s.
Subplots:		
Resistance	n.s.	n.s.
Resistance x Year	n.s.	***
Family x Resistance	n.s.	*
	500-KERNEL WEIGHT	
Main Plots:		
Years	n.s.	***
Replications	n.s.	n.s.
Families	n.s.	***
Subplots:		
Resistance	***	**
Resistance x Year	n.s.	***
Family x Resistance	n.s.	***

F values computed for years were very highly significant for each of the three components at Hutchinson and for yield at Manhattan. Years were an insignificant source of variation in test weights and kernel weights at Manhattan. Differences in mean performance between years are expected. The results indicate that environmental conditions at Hutchinson varied greatly enough to affect all three components whereas only yield was affected at Manhattan. The very highly significant families source of variation in yield for both combined experiments, and 500-kernel weight at the Hutchinson experiments indicate possible genetic differences among families.

Yield and 500-kernel weight differences between the resistant and susceptible lines were highly significant in both combined experiments. Relative test weight differences between the resistant and susceptible lines were nonsignificant at both locations. The significant resistance x year interaction at Hutchinson for all three components is a reflection of the differing behavior of the resistant and susceptible lines under different environmental circumstances. The resistance x family interaction was nonsignificant for all components at Manhattan and significant for relative test weight and 500-kernel weight at Hutchinson.

A summary of the combined analysis of two experiments grown in 1960 and 1961 indicated that leaf rust influenced yield and 500-kernel weight, families differed in performance ability for all components, and an unknown source of variation confounded with years resulted in heterogeneous experimental error in certain measurements.

DISCUSSION AND CONCLUSIONS

Many methods in the past have been utilized to evaluate the effect of a disease on a crop, Chester (1944 and 1950). Since the intensity of the disease and the corresponding loss are influenced by the ecological relationships of the host, fungus, and the environment, it is logical that a reliable measure of actual loss must be made under field conditions. Genetic, pathologic, and environmental factors are confounded in a manner which is extremely difficult to evaluate. Yields are often inconsistent with disease damage estimates due to the interaction of many factors both genetic and environmental which are not apparent. Isogenic lines of wheat differing in response to leaf rust, grown under field conditions, are theoretically a promising method to detect the effects of leaf rust on the yield components. The chief objection to comparisons of resistant and susceptible segregates from a hybridization is that there is a possibility of linkage and correlation of a nature that leaf rust response and some factor of yield importance do not segregate independently. Results of the sulphur experiment at Manhattan in 1961 show that lines used in this study were similar within families but differed among families for the four components of yield measured. The nonsignificance of F values for resistant lines within families indicated that differences which may be observed between the mean performance of resistant and susceptible lines under leaf rust attack are a valid measure of the disease damage. Additional evidence is provided by date of half-bloom and height data to support the similarity between resistant and susceptible lines. Examination of winter damage data recorded in 1960 shows that lines within families may differ somewhat for that characteristic. A disadvantage of the use of the sulphur treatment is that it also controls other diseases which may be associated with the experiments under leaf rust infection. The 1961 results showed that sulphur dusting controlled septoria. These findings are in agreement with Greaney (1934b) in that the true performance of lines under natural environmental conditions in the absence of one disease cannot be measured using sulphur.

The 1960 component of yield results at Manhattan were confounded by frost damage which thinned stands. Conclusions on the effect of leaf rust in replications I-III are complicated by the heavy stem rust infection.

The leaf rust infections in 1960 and 1961 were late in becoming established. In both years infections became established when plants were in the heading stage or later. Under these circumstances results do not reflect the true differences which may exist between resistant and susceptible lines grown in the presence of rust infections initiated in the early stages of plant development. Conclusions drawn from results obtained in this study must be made with precise reference to the character of the leaf rust infection.

Two experiments in 1960 indicate that leaf rust affected yield and 500-kernel weight but not test weight. The experiment under artificial infection in 1961 showed a leaf rust effect on yield and 500-kernel weight but no effect on relative test weight and kernels per spike. Late infections of 100 percent on the flag leaf in the artificial infection experiment make it apparent that the stage of development of the plant when it is infected determines the ultimate damage rather than the maximum infection just prior to drying of the leaves. These results are in agreement with Mains (1930), Johnston and Miller (1934), and Johnston (1931). They found that post-blossom damage is reflected as a reduction in kernel weight rather than test weight or kernels per head.

The results at Hutchinson in 1961 are an indication of the very light leaf rust infection at that location. The significant effect of leaf rust on test weight is difficult to explain because the susceptible lines outperformed the resistant lines. Leaf rust infections may have become established late and had the effect of pruning the plants under hot, dry, windy conditions. This effect may have been to the disadvantage of resistant plants with larger areas of transpiring leaf surface remaining.

The fact that reductions in test weights were not detected may indicate the physiologic effect of leaf rust on the development of the kernel. Results under light leaf rust infection show that plumpness of kernel was maintained while kernel weight was reduced. Similar findings have been reported by Caldwell (1934) and Waldron (1936) under heavier leaf rust infections.

Significant family x resistance interactions indicate that resistant and susceptible lines may not represent the same level of resistance to damage from one family to another. The visual response to the disease may be a poor criteria for classification of lines selected in a study of this type. The ability of certain genotypes to tolerate leaf rust may be a confounding factor which needs greater consideration in future studies. The studies of Caldwell et al., (1934) pointed out that the variety Fulhard was not reduced in yield even though it was severely rusted. Samborski and Peterson (1960) obtained 12-28 percent reduction in yield of resistant but not immune selections when they were grown in close proximity to heavily infected susceptible plants. Yield comparisons in studies comparing resistant and susceptible lines may be affected by this factor.

It is important to note that a study of this nature involves only one of the possible types of genetic resistance and one maturity classification. This approach to disease damage evaluation will be of greatest value only if the selections utilized in the study are representative of the wheat grown commercially in the area being evaluated.

The limited results of two years of replicated study indicate that the method of using resistant and susceptible segregates from a cross can detect leaf rust effect on yield under circumstances of late and light infection. Further evaluation of this method to include a greater representation of natural environmental conditions will be required to evaluate the accuracy of this approach to estimation of leaf rust damage. It is entirely feasible that in the future, rather than present day subjective estimates, a series of test plantings throughout an area will provide a better estimate of losses.

SUMMARY

A comparison of lines of hard red winter wheat, which were genetically similar but differing in leaf rust response, for yield components was made in 1960 and 1961 at Manhattan and Hutchinson.

Comparisons under sulphur treatment in 1961 showed that lines used in this study were similar within families but differed among families.

Leaf rust occurred late each season. Significant differences in yield and 500-kernel weight due to the additive effect of leaf rust were detected under natural infections in 1960 and artificial infection in 1961. Reductions in yield were due to reduction in kernel weight when damage was inflicted by the disease after the flowering stage of development.

Comparison of resistant and susceptible lines as a method of damage estimation will require further study to include natural environmental conditions which favor heavier leaf rust infections.

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APPENDIX

Table 1. Winter damage recorded on a scale of 0-10 taken April 18, 1960 on resistant and susceptible selections grown in two experiments at Manhattan in 1960.*

Selection No.		Rep I-III		Rep IV-VI		Mean	
R	S	R	S	R	S	R	S
59902	59901	6.0	5.6	6.6	6.6	6.3	6.1
59912	59911	7.3	6.0	8.6	7.0	8.0	6.5
59926	59925	4.6	4.3	5.6	5.6	5.1	5.0
59927	59928	7.6	7.6	9.0	8.6	8.4	8.1
59935	59936	6.3	5.3	6.6	6.0	6.4	5.6
59959	59960	6.0	7.0	7.0	8.0	6.5	7.5
59965	59966	6.0	6.6	7.3	8.6	6.6	7.6
	Mean	6.3	6.0	7.2	7.2	6.8	6.6

* R = Resistant lines, S = Susceptible lines

Table 2. Mean leaf rust percent and response and stem rust response readings taken on resistant and susceptible selections grown in three experiments in 1960.*

Selection No.	Leaf Rust			Stem Rust Response		
	Average percent		Response	Manhattan		Hutchinson
	Manhattan Rep IV-VI	Hutchinson Rep VII-IX	Manhattan Rep I-III	Rep I-III	Rep IV-VI	Rep VII-IX
59901	70	77	S	MR	MR	MR
59902	T	T	R	R	MR	MR
59911	73	70	S	SR	S	SR
59912	T	T	R	SR	S	SR
59925	77	73	S	S	S	S
59926	T	T	R	R	R	R
59927	T	2	R	MR	MR	MR
59928	80	73	S	MR	MR	MR
59935	T	T	R	R	MR	MR
59936	73	67	S	MR	MR	MR
59959	T	T	R	MR	MR	MR
59960	73	67	S	MR	MR	MR
59965	T	T	R	MR	MR	MR
59966	80	73	S	MR	MR	MR

* R - Resistant lines, S - Susceptible lines.

Table 3. Yields in grams of replicated resistant and susceptible selections grown under natural leaf rust infection at Manhattan in 1960, replications I-III.*

Selection No.		Rep I		Rep II		Rep III		Mean	
R	S	R	S	R	S	R	S	R	S
59902	59901	378	162	373	158	336	257	362.3	192.3
59912	59911	457	166	284	227	354	196	365.0	196.3
59926	59925	254	120	194	104	251	90	233.0	104.6
59927	59928	359	254	413	260	427	302	399.6	272.0
59935	59936	416	155	322	144	356	240	364.6	179.6
59959	59960	169	159	299	242	414	313	294.0	238.0
59965	59966	346	152	304	301	322	221	324.0	224.6
							Mean	334.6	201.5

* R = Resistant lines, S = Susceptible lines.

Table 4. Relative test weights in grams of replicated resistant and susceptible selections grown under natural leaf rust infection at Manhattan in 1960, replications I-III. *

Selection No.		Rep I		Rep II		Rep III		Mean	
R	S	R	S	R	S	R	S	R	S
59902	59901	24.10	22.38	24.16	22.66	24.24	22.67	24.17	22.57
59912	59911	23.86	22.91	23.91	22.71	23.87	22.63	23.88	22.75
59926	59925	23.79	20.48	23.77	21.64	24.50	21.68	24.02	21.27
59927	59928	24.12	23.82	23.75	23.68	24.01	24.07	23.96	23.86
59935	59936	24.71	22.09	24.46	23.06	24.60	24.15	24.59	23.10
59959	59960	23.96	23.13	23.98	23.43	24.20	23.37	24.05	23.31
59965	59966	28.78	23.02	23.15	24.30	23.91	23.46	25.28	23.59
							Mean	24.28	22.92

* R = Resistant lines, S = Susceptible lines

Table 5. The 500-kernel weights in grams of replicated resistant and susceptible selections grown under natural leaf rust infection at Manhattan in 1960, replications I-III.*

Selection No.		Rep I		Rep II		Rep III		Mean	
R	S	R	S	R	S	R	S	R	S
59902	59901	13.94	11.20	14.58	11.72	14.51	12.13	14.34	11.68
59912	59911	14.84	11.73	14.94	12.33	15.77	12.12	15.18	12.06
59926	59925	13.53	10.78	14.17	9.57	15.08	9.90	14.26	10.08
59927	59928	14.64	13.48	14.99	12.93	15.21	13.83	14.95	13.41
59935	59936	16.00	12.61	16.10	12.54	16.32	13.51	16.14	12.89
59959	59960	14.79	13.09	14.64	12.88	15.47	13.52	14.97	13.16
59965	59966	15.49	12.44	15.42	13.28	16.28	13.29	15.73	13.00
							Mean	15.08	12.33

* R = Resistant lines, S = Susceptible lines.

Table 6. Yields in grams of replicated resistant and susceptible selections grown under natural leaf rust infection at Manhattan in 1960, replications IV-VI.*

Selection No.		Rep IV		Rep V		Rep VI		Mean	
R	S	R	S	R	S	R	S	R	S
59902	59901	485	484	474	432	416	429	458.3	448.3
59912	59911	482	416	445	339	421	319	449.3	358.0
59926	59925	420	401	360	275	279	232	353.0	302.6
59927	59928	519	453	547	445	483	350	516.3	416.0
59935	59936	524	338	493	414	438	345	485.0	365.6
59959	59960	537	489	374	455	366	491	425.6	478.3
59965	59966	577	401	583	439	539	442	566.3	427.3
							Mean	464.8	399.4

* R = Resistant lines, S = Susceptible lines

Table 7. Relative test weights in grams of replicated resistant and susceptible selections grown under natural leaf rust infection at Manhattan in 1960, replications IV-VI.*

Selection No.		Rep IV		Rep V		Rep VI		Mean	
R	S	R	S	R	S	R	S	R	S
59902	59901	25.29	25.03	25.47	25.06	25.03	25.11	25.26	25.07
59912	59911	24.96	24.59	25.07	24.45	29.29	24.52	26.44	24.52
59926	59925	25.99**	24.28	24.84	23.30	25.13	23.33	25.32	23.64
59927	59928	25.28	25.10	25.03	25.19	24.85	24.63	25.05	24.97
59935	59936	25.36	24.86**	24.79	24.88	25.23	24.15	25.13	24.63
59959	59960	24.76	24.98	24.76	25.01	25.14	24.94	24.89	24.98
59965	59966	25.28	25.65	25.13	25.19	25.08	25.50	25.16	25.45
							Mean	25.32	24.75

* R - Resistant lines, S - Susceptible lines.
** Data computed using missing plot technique.

Table 8. The 500-kernel weights in grams of replicated resistant and susceptible selections grown under natural leaf rust infection at Manhattan in 1960, replications IV-VI.*

Selection No.		Rep IV		Rep V		Rep VI		Mean	
R	S	R	S	R	S	R	S	R	S
59902	59901	14.76	14.37	15.38	14.60	14.53	13.92	14.89	14.30
59912	59911	14.80	13.36	14.87	13.35	15.40	13.58	15.02	13.36
59926	59925	14.73	12.42	11.52	15.48	15.08	11.65	13.78	13.18
59927	59928	15.61	14.40	15.05	14.39	15.02	14.40	15.23	14.40
59935	59936	16.25	12.08**	15.81	14.43	15.62	14.07	15.89	13.53
59959	59960	14.49	14.60	14.45	14.49	14.94	13.91	14.63	14.33
59965	59966	15.31	14.59	14.82	14.16	15.59	14.00	15.24	14.25
							Mean	14.95	13.91

* R = Resistant lines, S = Susceptible lines.
** Data computed using missing plot technique.

Table 9. Yields in grams of replicated resistant and susceptible selections grown under natural leaf rust infection at Hutchinson in 1960, replications VII-IX.*

Selection No.		Rep VII		Rep VIII		Rep IX		Mean	
R	S	R	S	R	S	R	S	R	S
59902	59901	393	370	505	403	501	332	466.3	368.3
59912	59911	463	375	484	445	499	442	482.0	420.6
59926	59925	365	248	345	340	381	353	363.6	313.6
59927	59928	451	380	430	443	461	481	447.3	434.6
59935	59936	358	306	439	379	373	360	390.0	349.0
59959	59960	417	278	436	389	447	437	433.3	368.0
59965	59966	369	377	425	465	471	452	421.6	431.3
							Mean	429.2	383.6

* R = Resistant lines, S = Susceptible lines

Table 10. Relative test weights in grams of replicated resistant and susceptible selections grown under natural leaf rust infection at Hutchinson in 1960, replications VII-IX.*

Selection No.		Rep VII		Rep VIII		Rep IX		Mean	
R	S	R	S	R	S	R	S	R	S
59902	59901	25.05	24.61	25.10	25.53	25.02	24.61	25.06	24.92
59912	59911	25.00	23.68	25.19	24.67	25.48	24.25	25.22	24.20
59926	59925	25.42	23.33	24.61	23.76	24.92	24.34	24.98	23.81
59927	59928	24.49	24.36	24.72	25.14	24.38	24.68	24.53	24.73
59935	59936	25.39	24.42	24.92	25.01	24.77	24.46	25.03	24.63
59959	59960	24.77	25.08	24.82	24.35	24.97	24.40	24.85	24.61
59965	59966	24.50	25.18	24.46	25.28	25.26	24.98	24.74	25.15
							Mean	24.92	24.58

* R = Resistant lines, S = Susceptible lines.

Table 11. The 500-kernel weights in grams of replicated resistant and susceptible selections grown under natural leaf rust infection at Hutchinson in 1960, replications VII-IX.*

Selection No.		Rep VII		Rep VIII		Rep IX		Mean	
R	S	R	S	R	S	R	S	R	S
59902	59901	13.76	14.00	13.56	12.55	13.71	12.79	13.68	13.11
59912	59911	14.17	11.86	15.92	13.04	15.36	12.67	15.15	12.52
59926	59925	13.22	10.99	13.26	10.62	13.55	11.68	13.34	11.10
59927	59928	13.19	12.17	13.10	12.91	13.81	12.47	13.37	12.52
59935	59936	14.90	12.97	14.66	13.62	14.30	12.66	14.62	13.08
59959	59960	13.78	13.15	13.90	12.11	14.51	12.79	14.06	12.68
59965	59966	13.54	13.13	13.81	13.40	14.32	12.98	13.89	13.17
							Mean	14.02	12.60

* R = Resistant lines, S = Susceptible lines.

Table 12. The analysis of variance of each yield component for two experiments grown at Manhattan, replications I-III and IV-VI, and one experiment grown at Hutchinson, replications VII-IX, in 1960.

Source of variation	d.f.	Ss	Ms	F	Sig
Manhattan Yield Evaluation, Rep I-III.					
Main Plots:					
Replications	2	11,791.05	5,895.52	1.58	n.s.
Families	6	88,465.91	14,744.32	3.94	*
Error a	12	44,886.95	3,740.58		
Subplots:					
Resistance	1	187,333.93	187,333.93	60.16	***
Family x Resistance	6	18,683.23	3,113.87	1.14	n.s.
Error b	14	38,377.34	2,738.38		
Manhattan Test Weight Evaluation, Rep I-III.					
Main Plots:					
Replications	2	.32	.16	.23	n.s.
Families	6	11.47	1.91	2.78	n.s.
Error a	12	8.24	.69		
Subplots:					
Resistance	1	19.33	19.33	18.66	***
Family x Resistance	6	6.21	1.04	.98	n.s.
Error b	14	14.72	1.05		
Manhattan 500-kernel Weight Evaluation, Rep I-III.					
Main Plots:					
Replications	2	2.84	1.42	24.5	***
Families	6	25.69	4.82	73.8	***
Error a	12	.70	.058		

Table 12. (continued)

Source of variation	d.f.	Ss	Ms	F	Sig
Subplots:					
Resistance	1	79.62	79.62	66.35	***
Family x Resistance	6	7.23	1.20	6.32	***
Error b	14	2.60	.19		
Manhattan Yield Evaluation, Rep IV-VI.					
Main Plots:					
Replications	2	34,085.76	17,042.88	8.47	**
Families	6	107,541.34	17,923.56	8.90	***
Error a	12	24,157.24	2,013.10		
Subplots:					
Resistance	1	44,884.03	44,884.03	6.54	*
Family x Resistance	6	41,181.80	6,863.63	5.80	**
Error b	14	16,569.67	1,183.55		
Manhattan Test Weight Evaluation, Rep IV-VI.					
Main Plots:					
Replications	2	.60	.30	.40	n.s.
Families	6	3.80	.63	1.02	n.s.
Error a	12	7.39	.62		
Subplots:					
Resistance	1	3.44	3.44	2.99	n.s.
Family x Resistance	6	6.91	1.15	2.05	n.s.
Error b	12	6.68	.56		
Manhattan 500-kernel Weight Evaluation, Rep IV-VI.					
Main Plots:					
Replications	2	.07	.035	.29	n.s.
Families	6	7.87	1.31	8.19	***
Error a	12	1.99	.16		

Table 12. (continued)

Source of variation	d.f.	Ss	Ms	F	Sig
Subplots:					
Resistance	1	11.50	11.50	14.56	**
Family x Resistance	6	4.72	.79	.53	n.s.
Error B	13	19.24	1.48		
Hutchinson Yield Evaluation, Rep VII-IX.					
Main Plots:					
Replications	2	31,149.15	15,574.58	2.30	n.s.
Families	6	58,331.95	9,721.99	1.43	n.s.
Error a	12	8,139.19	6,782.66		
Subplots:					
Resistance	1	21,760.38	21,760.38	11.51	*
Family x Resistance	6	11,343.29	1,890.56	1.48	n.s.
Error b	14	17,916.33	1,279.74		
Hutchinson Test Weight Evaluation, Rep VII-IX.					
Main Plots:					
Replications	2	.18	.09	.79	n.s.
Families	6	1.44	.24	2.07	n.s.
Error a	12	1.40	.115		
Subplots:					
Resistance	1	1.21	1.21	2.34	n.s.
Family x Resistance	6	3.08	.51	3.52	*
Error b	14	2.04	.15		

Table 12. (continued)

Source of variation	d.f.	Ss	Ms	F	Sig
Hutchinson 500-kernel Weight Evaluation, Rep VII-IX.					
Main Plots:					
Replications	2	.27	.14	.38	n.s.
Families	6	11.72	1.95	5.27	**
Error a	12	4.45	.37		
Subplots:					
Resistance	1	21.10	21.10	22.69	***
Family x Resistance	6	5.56	.93	6.64	**
Error b	14	1.98	.14		

Table 13. Mean date of half-bloom in May of resistant and susceptible lines grown in two replicated experiments at Manhattan in 1961, replications I-III and IV-VI.*

Selection No.		Sulphur - Rep I-III		Natural Infection-Rep IV-VI	
R	S	R	S	R	S
59902	59901	27	28	27	27
59912	59911	28	26	28	26
59926	59925	26	28	27	27
59927	59928	28	29	28	29
59935	59936	26	25	26	26
59959	59960	26	27	26	26
59965	59966	27	28	27	27
	Mean	27	27	27	27

* R = Resistant lines, S = Susceptible lines.

Table 14. Mean height in inches of resistant and susceptible lines grown in two replicated experiments at Manhattan, sulphur and artificial infection, and under natural infection at Hutchinson in 1961.*

Selection No.		Manhattan				Hutchinson	
		Sulphur Rep I-III		Artificial Infection Rep IV-VI		Natural Infection Rep VII-IX	
R	S	R	S	R	S	R	S
59902	59901	39	40	40	39	39	38
59912	59911	39	38	39	38	37	37
59926	59925	38	37	40	37	38	38
59927	59928	37	36	38	37	37	36
59935	59936	38	37	39	36	38	37
59959	59960	37	37	37	37	36	37
59965	59966	38	39	38	39	38	38
	Mean	38	37	39	38	38	37

* R = Resistant lines, S = Susceptible lines.

Table 15. Mean leaf rust percent for the two Manhattan experiments, sulphur and artificial infection, and stem rust response for the artificial infection experiment at Manhattan and the natural infection experiment at Hutchinson in 1961.*

Selection No.		Percent Leaf Rust				Stem Rust Response			
		Manhattan				Manhattan		Hutchinson	
		Sulphur Rep I-III		Artificial Infection Rep IV-VI		Artificial Infection Rep IV-VI		Natural Infection Rep VII-IX	
R	S	R	S	R	S	R	S	R	S
59902	59901	T**	T	T	37	R	R	R	R
59912	59911	T	T	T	40	S	S	S	S
59926	59925	T	T	T	47	R	S	R	S
59927	59928	T	T	T	53	R	R	R	R
59935	59936	T	T	T	37	R	R	R	R
59959	59960	T	T	T	50	R	R	R	R
59965	59966	T	T	T	63	R	R	R	R

* R - Resistant lines, S - Susceptible lines.
** Trace

Table 16. Yields in grams of replicated resistant and susceptible selections grown under sulphur treatment at Manhattan in 1961, replications I-III.*

Selection No.		Rep I		Rep II		Rep III		Mean	
R	S	R	S	R	S	R	S	R	S
59902	59901	691	734	690	723	690	705	690.3	720.6
59912	59911	813	780	742	787	717	722	757.3	763.0
59926	59925	698	639	756	723	758	745	737.3	702.3
59927	59928	750	738	856	679	806	764	804.0	727.0
59935	59936	626	731	638	714	737	672	667.0	705.6
59959	59960	713	716	706	681	742	688	720.3	695.0
59965	59966	774	767	764	763	782	754	773.3	761.3
							Mean	735.6	725.0

* R - Resistant lines, S - Susceptible lines.

Table 17. Relative test weights in grams of replicated resistant and susceptible selections grown under sulphur treatment at Manhattan in 1961, replications I-III.*

Selection No.		Rep I		Rep II		Rep III		Mean	
R	S	R	S	R	S	R	S	R	S
59902	59901	24.76	25.12	25.08	24.48	25.45	24.80	25.10	24.80
59912	59911	25.66	25.79	25.39	25.59	25.41	25.64	25.49	25.67
59926	59925	25.22	25.28	25.29	25.24	25.12	25.34	25.21	25.29
59927	59928	25.54	25.49	25.40	25.20	24.92	25.41	25.29	25.37
59935	59936	25.56	25.13	25.88	25.23	25.47	25.79	25.64	25.38
59959	59960	25.78	25.50	25.39	25.82	25.28	25.88	25.48	25.73
59965	59966	25.24	25.30	25.44	25.69	25.36	25.74	25.35	25.58
							Mean	25.36	25.40

* R = Resistant lines, S = Susceptible lines.

Table 18. The 500-kernel weights in grams of replicated resistant and susceptible selections grown under sulphur treatment at Manhattan in 1961, replications I-III.*

Selection No.		Rep I		Rep II		Rep III		Mean	
R	S	R	S	R	S	R	S	R	S
59902	59901	14.31	14.68	14.64	15.00	14.72	15.05	14.56	14.91
59912	59911	16.25	15.72	16.56	15.68	17.03	14.87	16.61	15.42
59926	59925	15.92	15.32	15.48	15.35	15.24	15.43	15.55	15.37
59927	59928	16.56	16.03	16.36	15.83	16.23	16.37	16.38	16.08
59935	59936	15.14	15.57	15.48	15.42	15.33	15.15	15.32	15.38
59959	59960	15.61	15.50	15.26	15.40	15.42	15.82	15.43	15.57
59965	59966	16.13	15.04	16.04	15.11	16.10	14.90	16.09	15.02
							Mean	15.70	15.39

* R - Resistant lines, S - Susceptible lines.

Table 19. The mean number of kernels per spike of three randomly selected spikes from replicated resistant and susceptible selections grown under sulphur treatment at Manhattan in 1961, replications I-III.*

Selection No.		Rep I		Rep II		Rep III		Mean	
R	S	R	S	R	S	R	S	R	S
59902	59901	17.00	17.75	16.25	21.00	20.25	17.50	17.83	18.75
59912	59911	17.00	22.25	17.75	16.25	14.25	15.25	16.33	17.92
59926	59925	17.00	21.75	19.25	21.00	15.25	20.25	17.17	21.00
59927	59928	17.00	18.75	17.00	16.25	16.25	20.00	16.75	18.33
59935	59936	18.50	15.50	17.75	17.75	17.00	15.75	17.75	16.33
59959	59960	18.00	17.25	20.50	17.25	15.75	16.75	18.08	17.08
59965	59966	18.00	16.25	15.75	18.75	17.00	18.25	16.92	17.75
							Mean	17.26	18.17

* R = Resistant lines, S = Susceptible lines.

Table 20. Yields in grams of replicated resistant and susceptible selections grown under artificial infection at Manhattan in 1961, replications IV-VI.*

Selection No.		Rep IV		Rep V		Rep VI		Mean	
R	S	R	S	R	S	R	S	R	S
59902	59901	592	529	630	539	587	555	603.0	541.0
59912	59911	590	558	643	594	553	559	595.3	570.3
59926	59925	585	547	561	514	559	551	568.3	537.3
59927	59928	674	525	679	607	664	617	672.3	583.0
59935	59936	553	500	561	539	628	587	580.6	542.0
59959	59960	619	523	603	544	553	591	591.6	552.6
59965	59966	567	539	650	611	667	702	628.0	617.3
							Mean	605.6	563.4

* R = Resistant lines, S = Susceptible lines.

Table 21. Relative test weight in grams of replicated resistant and susceptible selections grown under artificial infection at Manhattan in 1961, replications IV-VI.*

Selection No.		Rep IV		Rep V		Rep VI		Mean	
R	S	R	S	R	S	R	S	R	S
59902	59901	25.03	25.46	25.15	24.94	25.16	25.27	25.11	25.22
59912	59911	25.31	25.70	25.36	25.40	24.86	24.53	25.18	25.21
59926	59925	24.72	25.03	25.10	24.44	24.96	24.47	24.93	24.65
59927	59928	25.46	25.45	25.24	25.19	25.06	25.30	25.25	25.31
59935	59936	25.61	25.58	25.46	24.86	24.97	25.22	25.35	25.22
59959	59960	25.39	25.51	25.84	25.09	25.34	25.26	25.52	25.29
59965	59966	25.57	24.76	25.59	25.21	25.23	25.15	25.46	25.04
							Mean	25.26	25.13

* R = Resistant lines, S = Susceptible lines.

Table 22. The 500-kernel weight in grams of replicated resistant and susceptible selections grown under artificial infection at Manhattan in 1961, replications IV-VI.*

Selection No.		Rep IV		Rep V		Rep VI		Mean	
R	S	R	S	R	S	R	S	R	S
59902	59901	13.21	13.96	13.02	12.97	13.68	13.53	13.30	13.49
59912	59911	14.59	13.76	15.73	13.23	14.60	12.18	14.97	13.06
59926	59925	12.66	13.12	14.83	12.26	13.21	12.07	13.57	12.48
59927	59928	14.79	13.80	14.95	13.58	15.04	13.71	14.93	13.70
59935	59936	14.36	13.39	13.99	11.54	14.69	14.04	14.35	12.99
59959	59960	14.16	13.99	14.45	12.95	13.59	13.06	14.07	13.33
59965	59966	14.74	12.17	14.57	12.84	15.03	13.32	14.78	12.78
							Mean	14.28	13.12

* R = Resistant lines, S = Susceptible lines

Table 23. The mean number of kernels per spike of three randomly selected spikes from replicated resistant and susceptible selections grown under artificial infection at Manhattan in 1961, replications IV-VI.*

Selection No.		Rep IV		Rep V		Rep VI		Mean	
R	S	R	S	R	S	R	S	R	S
59902	59901	16.00	19.25	13.75	16.75	19.75	18.50	16.50	18.17
59912	59911	18.00	18.25	11.50	23.00	17.00	19.75	15.50	20.33
59926	59925	20.75	18.25	14.75	23.25	19.00	17.00	18.17	19.50
59927	59928	17.25	17.25	18.50	17.50	21.00	14.25	18.92	16.33
59935	59936	18.25	16.00	15.75	16.50	17.75	17.75	17.25	16.75
59959	59960	17.25	15.50	15.25	17.00	16.00	16.50	16.17	16.33
59965	59966	16.00	14.25	18.50	13.50	18.25	15.50	17.57	14.42
							Mean	17.15	17.40

* R = Resistant lines, S = Susceptible lines.

Table 24. Yields in grams of replicated resistant and susceptible selections grown under natural infection at Hutchinson in 1961, replications VII-IX.*

Selection No.		Rep VII		Rep VIII		Rep IX		Mean	
R	S	R	S	R	S	R	S	R	S
59902	59901	594	445	488	498	564	573	548.6	505.3
59912	59911	536	588	538	522	571	633	548.3	581.0
59926	59925	464	516	504	607	625	513	531.0	545.3
59927	59928	451	537	565	555	649	592	555.0	561.3
59935	59936	471	515	499	483	651	600	540.3	532.6
59959	59960	490	680	425	499	563	580	492.6	586.3
59965	59966	617	636	604	518	689	607	636.6	587.0
							Mean	550.3	557.0

* R = Resistant lines, S = Susceptible lines.

Table 25. Relative test weight in grams of replicated resistant and susceptible selections grown under natural infection at Hutchinson in 1961, replications VII-IX.*

Selection No.		Rep VII		Rep VIII		Rep IX		Mean	
R	S	R	S	R	S	R	S	R	S
59902	59901	25.22	25.67	25.67	25.59	25.30	25.47	25.40	25.58
59912	59911	25.52	25.79	25.88	25.46	25.20	25.51	25.53	25.59
59926	59925	25.08	25.17	25.65	26.41	25.36	25.62	25.36	25.73
59927	59928	25.53	25.48	25.59	25.79	25.67	25.32	25.60	25.86
59935	59936	25.99	25.46	25.83	25.98	25.56	25.86	25.79	25.77
59959	59960	25.66	25.88	25.67	25.74	25.66	25.61	25.66	25.74
59965	59966	25.39	25.99	25.49	26.14	25.66	26.10	25.51	26.08
							Mean	25.55	25.76

* R = Resistant lines, S.= Susceptible lines.

Table 26. The 500-kernel weight in grams of replicated resistant and susceptible selections grown under natural infection at Hutchinson in 1961, replications VII-IX.*

Selection No.		Rep VII		Rep VIII		Rep IX		Mean	
R	S	R	S	R	S	R	S	R	S
59902	59901	13.82	14.46	13.97	14.99	13.80	13.68	13.86	14.38
59912	59911	14.20	14.30	14.77	14.48	14.95	13.46	14.64	14.08
59926	59925	14.49	14.10	14.89	13.54	14.15	12.80	14.51	13.48
59927	59928	14.35	14.29	14.72	14.34	14.91	14.36	14.66	14.33
59935	59936	15.14	15.12	14.89	14.96	13.52	14.98	14.52	15.02
59959	59960	14.16	13.18	14.39	14.39	14.27	13.82	14.27	13.80
59965	59966	14.84	13.86	15.30	14.81	13.77	13.61	14.64	14.09
							Mean	14.44	14.17

* R = Resistant lines, S = Susceptible lines.

Table 27. The mean number of kernels per spike of three randomly selected spikes from replicated resistant and susceptible selections grown under natural infection at Hutchinson in 1961, replications VII-IX.*

Selection No.		Rep VII		Rep VIII		Rep IX		Mean	
R	S	R	S	R	S	R	S	R	S
59902	59901	16.00	17.00	17.50	16.75	14.25	17.25	15.92	17.00
59912	59911	17.00	15.75	21.25	16.00	16.00	20.50	18.08	17.42
59926	59925	15.50	17.00	16.00	16.75	19.50	14.50	17.00	16.08
59927	59928	16.25	15.75	20.75	15.75	16.75	14.00	17.92	15.17
59935	59936	13.25	13.25	19.50	17.00	17.75	15.75	16.83	15.33
59959	59960	15.75	16.25	14.50	15.00	17.75	17.50	16.00	16.25
59965	59966	16.50	20.75	13.50	14.50	16.50	16.75	15.50	17.33
							Mean	16.75	16.37

* R = Resistant lines, S = Susceptible lines

Table 28. The analysis of variance of each yield component for two experiments grown at Manhattan, replications I-III and IV-VI, and one experiment grown at Hutchinson, replications VII-IX, in 1961.

Source of Variation	d.f.	Ss	Ms	F	Sig
Manhattan Sulphur, Yield Evaluation, Rep I-III.					
Main Plots:					
Replications	2	448	224	.16	n.s.
Families	6	40,034	6,672	4.66	**
Error a	12	17,157	1,430		
Subplots:					
Resistance	1	1,194	1,194	.50	n.s.
Family x Resistance	6	14,387	2,398	1.78	n.s.
Error b	14	18,815	1,344		
Manhattan Sulphur, Test Weight Evaluation, Rep I-III.					
Main Plots:					
Replications	2	.0086	.0043	.10	n.s.
Families	6	1.9329	.3222	7.71	***
Error a	12	.5022	.0418		
Subplots:					
Resistance	1	.0161	.0161	.21	n.s.
Family x Resistance	6	.4560	.0760	1.09	n.s.
Error b	14	.9792	.0699		
Manhattan Sulphur, 500-kernel Weight Evaluation, Rep I-III.					
Main Plots:					
Replications	2	0.00	0.00	0.0	n.s.
Families	6	8.40	1.40	33.3	***
Error a	12	.50	.042		
Subplots:					
Resistance	1	1.03	1.03	1.94	n.s.
Family x Resistance	6	3.17	.53	5.76	***
Error b	14	1.29	.092		

Table 28. (continued)

Source of Variation	d.f.	Ss	Ms	F	Sig
Manhattan Sulphur, Kernels per Spike Evaluation, Rep I-III					
Main Plots:					
Replications	2	7.7500	3.8750	1.28	n.s.
Families	6	19.1964	3.1994	1.06	n.s.
Error a	12	36.1875	3.0156		
Subplots:					
Resistance	1	8.5952	8.5952	1.86	n.s.
Family x Resistance	6	27.7798	4.6300	1.39	n.s.
Error b	14	46.6875	3.3348		
Manhattan Yield Evaluation, Rep IV-VI.					
Main Plots:					
Replications	2	8,864	4,432	2.26	n.s.
Families	6	31,024	5,171	2.64	n.s.
Error a	12	23,498	1,958		
Subplots:					
Resistance	1	18,733	18,733	18.49	**
Family x Resistance	6	6,078	1,013	1.23	n.s.
Error b	14	11,534	824		
Manhattan Test Weight Evaluation, Rep IV-VI.					
Main Plots:					
Replications	2	.5175	.2588	3.87	n.s.
Families	6	1.3822	.2304	3.45	*
Error a	12	.8013	.0668		
Subplots:					
Resistance	1	.1598	.1598	2.66	n.s.
Family x Resistance	6	.3600	.0600	.80	n.s.
Error b	14	1.0549	.0754		

Table 28. (continued)

Source of Variation	d.f.	Ss	Ms	F	Sig
Manhattan 500-kernel Weight Evaluation, Rep IV-VI.					
Main Plots:					
Replications	2	.1146	.0573	.11	n.s.
Families	6	6.1749	1.0292	1.96	n.s.
Error a	12	6.3025	.5252		
Subplots:					
Resistance	1	14.1985	14.1985	17.11	**
Family x Resistance	6	4.9796	.8299	2.27	n.s.
Error b	14	5.1081	.3649		
Manhattan Kernels per Spike Evaluation, Rep IV-VI.					
Main Plots:					
Replications	2	5.5923	2.7962	1.70	n.s.
Families	6	34.3066	5.7178	3.47	*
Error a	12	19.7827	1.6486		
Subplots:					
Resistance	1	.6562	.6562	.59	n.s.
Family x Resistance	6	66.6875	11.1145	1.53	n.s.
Error b	14	101.5000	7.2500		
Hutchinson Yield Evaluation, Rep VII-IX.					
Main Plots:					
Replications	2	48,408	24,204	8.07	**
Families	6	29,828	4,971	1.66	n.s.
Error a	12	36,004	3,000		
Subplots:					
Resistance	1	460	460	.13	n.s.
Family x Resistance	6	21,274	3,546	1.19	n.s.
Error b	14	41,729	2,981		

Table 28. (continued)

Source of Variation	d.f.	Ss	Ms	F	Sig
Hutchinson Test Weight Evaluation, Rep VII-IX.					
Main Plots:					
Replications	2	.3445	.1722	2.02	n.s.
Families	6	.5513	.0919	1.08	n.s.
Error a	12	1.0238	.0853		
Subplots:					
Resistance	1	.4736	.4736	7.52	*
Family x Resistance	6	.3777	.0630	1.24	n.s.
Error b	14	.7121	.0509		
Hutchinson 500-kernel Weight Evaluation, Rep VII-IX.					
Main Plots:					
Replications	2	2.4962	1.2481	6.12	*
Families	6	2.7638	.4606	2.29	n.s.
Error a	12	2.4164	.2014		
Subplots:					
Resistance	1	.7927	.7927	1.59	n.s.
Family x Resistance	6	2.9913	.4985	2.80	n.s.
Error b	14	2.4921	.1780		
Hutchinson Kernels per Spike Evaluation, Rep VII-IX.					
Main Plots:					
Replications	2	3.6458	1.8229	.31	n.s.
Families	6	11.1845	1.8641	.32	n.s.
Error a	12	70.0209	5.8351		
Subplots:					
Resistance	1	1.5238	1.5238	.41	n.s.
Family x Resistance	6	22.0179	3.6696	.99	n.s.
Error b	14	51.7083	3.6934		

Table 29. The analysis of variance on combined data from the Manhattan experiments, replications IV-VI, grown under natural infection in 1960 and artificial infection in 1961.

Source of Variation	d.f.	Ss	Ms	F	Sig
		Yield			
Main Plots:					
Years	1	487,314.16	487,314.16	137.99	***
Replications	2	5,265.20	2,632.60	.74	n.s.
Families	6	110,900.36	18,483.39	5.23	***
Error a	32	113,003.78	3,531.36		
Subplots:					
Resistance	1	60,804.79	60,804.79	17.51	**
Year x Resistance	1	2,811.83	2,811.83	1.75	n.s.
Family x Resistance	6	20,837.85	3,472.97	2.16	n.s.
Error b	34	54,526.53	1,603.72		
		Test Weight			
Main Plots:					
Years	1	.54	.54	1.69	n.s.
Replications	2	.45	.22	.69	n.s.
Families	6	3.80	.63	1.97	n.s.
Error a	32	10.24	.32		
Subplots:					
Resistance	1	2.53	2.53	4.52	n.s.
Year x Resistance	1	1.07	1.07	2.97	n.s.
Family x Resistance	6	3.36	.56	1.56	n.s.
Error b	32*	11.64	.36		

Table 29. (continued)

Source of Variation	d.f.	Ss	Ms	F	Sig
		500-kernel Weight			
Main Plots:					
Years	1	11.24	11.24	.33	n.s.
Replications	2	.03	.015	.04	n.s.
Families	6	11.62	1.94	.06	n.s.
Error a	32	10.87	.34		
Subplots:					
Resistance	1	25.64	25.64	21.19	***
Year x Resistance	1	.06	.06	.04	n.s.
Family x Resistance	6	7.28	1.21	.70	n.s.
Error b	33**	56.76	1.72		

* Two missing plots in 1960.
** One missing plot in 1960.

Table 30. The analysis of variance on combined data from the Hutchinson experiments, replications VII-IX, grown under natural leaf rust infection in 1960 and 1961.

Source of Variation	d.f.	Ss	Ms	F	Sig
		Yield			
Main Plots:					
Years	1	455,407	455,407	198.00	***
Replications	2	54,426	27,213	11.83	***
Families	6	63,832	10,638	4.62	***
Error a	32	73,600	2,300		
Subplots:					
Resistance	1	7,946	7,946	21.54	***
Year x Resistance	1	14,274	14,274	4.41	*
Family x Resistance	6	2,214	369	.11	n.s.
Error b	34	110,049	3,236		
		Test Weight			
Main Plots:					
Years	1	17.43	17.43	170.59	***
Replications	2	.51	.255	2.50	n.s.
Families	6	1.17	.195	1.91	n.s.
Error a	32	3.27	.102		
Subplots:					
Resistance	1	.086	.086	.24	n.s.
Year x Resistance	1	1.59	1.59	13.25	***
Family x Resistance	6	2.13	.35	2.95	*
Error b	34	4.09	.12		

Table 30. (continued)

Source of Variation	d.f.	Ss	Ms	F	Sig
		500-kernel Weight			
Main Plots:					
Years	1	20.94	20.94	52.88	***
Replications	2	1.04	.52	1.31	n.s.
Families	6	10.41	1.73	4.36	***
Error a	32	12.66	.40		
Subplots:					
Resistance	1	15.03	15.03	14.45	**
Year x Resistance	1	6.86	6.86	34.30	***
Family x Resistance	6	6.27	1.04	5.20	***
Error b	34	6.77	.20		

THE EFFECT OF LEAF RUST ON THE COMPONENTS OF YIELD AND OTHER CHARACTERISTICS OF HARD RED WINTER WHEAT

by

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B.S., Iowa State University, 1960

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ABSTRACT

Leaf rust of wheat, Puccinia recondita Rob. ex Desm., is considered to cause substantial reductions in grain yield in certain years. A sound experimental procedure conducted under natural field conditions is needed to properly evaluate the effects of the leaf rust pathogen. This study attempts to evaluate a method and use that method to estimate the effects of leaf rust on hard red winter wheat strains varying in resistance.

An attempt was made to estimate the effect of the leaf rust organism on four components of yield using resistant and susceptible sister lines which originated from a single hybridization. A resistant and a susceptible line selected from the segregating progeny of an F_2 plant formed a family of sister lines which were nearly isogenic but differing in rust response.

Three experiments, each consisting of three replicates of the seven families planted in a split-plot design, were conducted in 1960 and 1961. An experiment under sulphur treatment and an experiment under artificial infection were planned for Manhattan. An experiment under natural leaf rust was planned for Hutchinson.

An analysis of variance to determine significant effects of the family, replication, resistance, and family x resistance sources of variability was conducted for each component for each experiment. The main plot analysis was that of randomized blocks with seven families replicated in three replications. The subplot analysis was the two levels of resistance randomized in each of the twenty-one main plots. The major object of the analysis

of variance was to detect any significant fixed added effect of leaf rust on yield, test weight, 500-kernel weight, and kernels per spike in each of the three experiments. An analysis of variance combining 1960 and 1961 data for similar experiments was conducted.

Leaf rust infections in 1960 and 1961 became established when plants were in the flowering stage or later.

The three experiments grown in 1960 were subjected to natural leaf rust infection. The 1961 experiments were conducted as planned. Under sulphur treatment the lines used in this study differed in performance among families but were similar in performance within families. In two experiments under natural leaf rust in 1960 and one experiment under artificial infection in 1961, leaf rust reduced yield and 500-kernel weight. Significant reductions in test weight and kernels per spike due to leaf rust were not detected. The combined analysis of two experiments grown in 1960 and 1961 also indicated that leaf rust influenced yield and kernel weight but not test weight.

The limited results of two years of replicated study indicate that the method of using resistant and susceptible segregates from a cross can detect leaf rust effect on yield under circumstances of late but heavy infection. Further evaluation of this method to include a greater representation of environmental conditions will be required to fully evaluate the accuracy of this approach to estimation of leaf rust damage.