HETEROSIS, INBREEDING DEPRESSION AND COMBINING ABILITY ESTIMATES FROM DIALLEL CROSSES IN HARD RED WINTER WHEAT

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CHAPTER I

INTRODUCTION

For a highly self-fertilizing species like wheat, two requirements should be satisfied to insure the success of commerical production of hydbrids. First, there must be heterosis for grain yield, and second, an economical large-scale method of producing hybrid seed must be found. The level of heterosis of the best hybrids so far evaluated appears to be of the same order as that found in hybrid sorghum and hybrid corn. The currently available cytoplasmic male sterile-restorer system in wheat offers a mechanism for producing hybrid seed. A recently reported chemical gametocide system, if perfected, provides an additional hybrid seed producing mechanism (38). If hybrid wheat production is to be reality in the foreseeable future, advances must be made in identifying parental lines that result in hybrid combinations exhibiting heterosis for grain yield. The extent of inbreeding depression in wheat would also be an important consideration in hybrid wheat production if the production of hybrid seed proves to be too expensive for widespread commercial utilization. In this event, perhaps the F_2 would provide sufficient heterosis to warrant its use commercially.

Of particular importance in any breeding program will be the choice of breeding method for the genetic improvement of important quantitative traits. To reach maximum progress per unit of time, the breeding procedures used must be adapted to the type of gene action involved. The diallel analysis technique allows the breeder to estimate the relative importance of general and specific combining ability for important agronomic characteristics in terms of the nature of gene action. Information on these systems is of value in the development of wheat hybrids as well as in the development of pure-line varieties.

Test of crosses in the early generation of self-pollinated crops are rationalized on the premise that the performance of such hybrid progenies predicts true potential of the crosses in later generations. Identifications of superior crosses in the F_1, F_2, and F_3 generation would result in more efficient breeding programs.

The primary objectives of this study were: 1) to determine the level of heterosis in F_1 hybrids and inbreeding depression in the corresponding F_2 populations in a series of hard red winter wheat crosses, 2) to estimate general and specific combining ability for important agronomic characters since these estimates indicate importance of additive and non-additive gene action, and 3) to determine the relationship between midparent, F_1 and F_2 and between F_2 and F_3 generations for various characters as a possible means of predicting potential value of a population in early generations.

CHAPTER II

REVIEW OF LITERATURE

Heterosis and Inbreeding Depression in Wheat

Interest in the level of heterosis manifested in wheat has been stimulated by the discovery of cytoplasmic male sterility and genetic systems for fertility restoration in hexaploid wheat. Briggle (5) made a comprehensive review of heterosis in wheat and cited instances of heterosis for yield up to 84% above the highest yielding parent. Heterosis for other agronomic characters including components of yield, plant height, and maturity was also reported. He emphasized that since nearly all of the earlier heterosis studies in wheat had been conducted with space-plants or small plots, these data are of limited value as a basis for decisions as to the feasibility of commercial hybrid wheat.

Brown, *et al.* (9) observed heterosis in a study of inter-class crosses among seven hard and soft winter wheat varieties grown in a hill-plot experiment. They reported the presence of high-parent and midparent heterosis for certain agronomic and quality characteristics. The mean yield of the F_1 hybrids ranged from 96 to 131% of the high-parent means. It was noted that much less heterosis occurred for components of yield than was observed fro grain yield itself. The mean protein content of the hybrids was 97% of the high-parent and 100% of the midparent values indicating that hybrids may exhibit heterosis for grain yield without suffering a significant decrease in percent protein.

Johnson, *et al.* (22) studied F_1 and F_2 populations of a tall x semidwarf wheat cross under space-planted conditions. Both F_1 and F_2 means for yield and number of spikes exceeded that of either parent. The mean yield of the F_1 was 12.9% above that of the high-parent. The F_1 mean for kernel weight was significantly greater than that of either parent, and the F_2 mean for this trait approached that of the high-parent. No heterosis was observed for number of kernels per spike. They reported that increased kernel weight, and to some extent, increased spike number accounted for the higher yield of the hybrid.

Under near-normal field testing prcoedures Livers and Heyne (30) noted that 18 hybrids averaged 20% above the mean value of seven parents for yield. The best hybrids yielded 33 and 29% more than the best parent in 1964 and 1965, respectively. They concluded that certain hard red winter wheat hybrids, grown under near-solid seeding rates, could express significant heterosis for yield.

Fonseca and Patterson (12) evaluated F_1 and F_2 wheat populations for important agronomic characters and examined the suitability of hill-planting techniques for determining heterosis in early stages of hybrid wheat research when seed is limited. Both the F_1 and F_2 hybrids expressed significant high-parent heterosis for grain yield, kernel weight, and number of spikes. The mean yield for all F_1's was 124% of the high-parent average in the 1963 test, and 128% in the 1964 test. The F_2 yields were generally lower than those of F_1's but higher than the parents. The mean yield of all F_2's was 12% better than the high-parent mean under hill-planting but only 2% above the high-parent mean at normal seeding rates. They concluded that the degree of heterosis tended to be overestimated to some extent in hill-planted plots.

Gyawali, et al. (17) studied heterosis and combining ability of inter-class F_1 hybrids in a space-planted experiment for important agronomic and quality characteristics. The range for grain yield of the 21 F_1 hybrids was 86 to 176% of the respective high-parent values. The mean yield of all F_1's was 24% greater than the high-parent average. The greatest heterosis for grain yield occurred in early x late hybrids. Milling and baking quality prediction tests of soft wheat hybrids were generally intermediate to that of the parents. They concluded that inter-class diversity is not necessary for expression of heterosis, since soft red winter x soft red winter hybrids were similar in heterosis values to soft red winter x hard red winter hybrids.

Glover and Smith (14) studied heterosis of several agronomic traits in eight wheat hybrids. Three of the eight hybrids exhibited significant high-parent heterosis of 16 to 18%; however, no hybrid significantly outyielded the best check variety in the test. All hybrids were significantly lower in spike number than their respective midparent value while seven of the eight hybrids were equal to their respective midparents for kernels per spike. Only one hybrid had a lower kernel weight than the best check variety. It was concluded from this study that increased kernel weight accounted for increased yield of the hybrids.

Wells and Lay (50) tested F_1 and F_2 generations of 22 spring wheats crossed with two adapted varieties of hard red spring wheats, 'Lee' and 'Rushmore' under solid-seeding rates. The best F_1 hybrid yielded 82 and 61% higher than its high-parent in 1965 and 1967, respectively. Only three F_2's were higher in yield than their respective high parents. They concluded that some F_1 combinations consistently showed substantial levels of heterosis and hence the development of productive hybrid spring bread wheats should be possible.

Walton (48) studied heterosis and combining ability in two different diallel crosses involving spring wheat cultivars of Canadian, Mexican, and U. S. origin at normal seeding rates. In an eight-parent diallel cross, the highest yielding F_1 hybrid was 8% better than its high-parent, 'Pitic 62', the best parent variety in the test, although this difference was not significant. In a five-parent diallel cross, all but two hybrids yielded between 15% and 88% more than their respective high parents. It was concluded that increased spike number accounted for the higher yields of the hybrids.

Bitzer and Fu (4) studied heterosis and combining ability in a diallel cross involving six soft red winter wheat varieties under hill-planted conditions. They found that three F_1 hybrids yielded significantly higher than their respective high parents. The range for yield for 15 F_1 hybrids was 94 to 130% of the high-parent values. The mean yield of all F_1's was 10% greater than the high-parent average. It was noted that much less heterosis occurred for components of yield than was observed for grain yield.

A decrease in performance of the F_2 from that of the F_1 has been reported by several workers in the literature but in all cases the main objective of these reports was to determine the level of heterosis in F_1 hybrids. Therefore, at the present time, information on inbreeding depression in wheat is very much limited.

Briggle, et al. (6) evaluated a spring wheat hybrid 'Lemi 53' x 'Henry' for yield and yield components in the F_1 and F_2 generations at five population density levels. They found that the F_1 produced (over all population levels) 19.2 and 16.5% more grain than the high-parent in

1964 and 1965, respectively. The F_2 was similar to its midparent in 1964 but was slightly higher than its high-parent in 1965. The F_2 hybrid was 27 and 11% lower in grain yield than the F_1 hybrid in 1964 and 1965, respectively. They also reported inbreeding depression values of 20 and 12% for number of spikes in 1964 and 1965, respectively. No heterosis and no inbreeding depression was expressed for number of kernels/spike. The F_2 hybrid showed a slight inbreeding depression (4%) for kernel size in 1964 but not in 1965. A similar experiment, involving a winter wheat hybrid 'Reed' x 'Gaines' was reported by Briggle, et al. (7). When means over all five population levels were compared, the F_1 yield was 28.9% greater than the higher parent in 1964, and 6.5% greater than the higher parent in 1965. The F_1 produced significantly more grain yield than the F_2 in both years. The inbreeding depression observed in the F_2 generation for yield was 43 and 21% for 1964 and 1965, respectively. The F_1 was similar in number of spikes to its high-parent for both years but significantly higher than the F_2 both years. Inbreeding depression for this character was 30 and 27% for 1964 and 1965, respectively. The F_2 was 10% lower in number of kernels/spike than the F_1 in 1964. However, this difference was not significant. In kernel weight, the F_2 was 6 and 5% lower than the F_1 in 1964 and 1965, respectively. However, this difference was significant only in the 1964 test.

Fonseca and Patterson (12) studied the performance of F_1 and F_2 generations of a seven-parent diallel cross under hill-planted conditions. The F_1 hybrids were superior to their respective high parents in 19 of the 21 cases. High-parent heterosis for yield of F_2 hybrids was significant in 11 of 21 cases. The mean of all 21 F_1 hybrids was 22% better than the high-parent mean while the mean of all 21 F_2 hybrids was 12%

better than the high-parent mean. This indicates an average degree of inbreeding depression of 11%. No inbreeding depression was observed for number of spikes or kernels/spike. For kernel weight, some inbreeding depression (5%) occurred.

In a spring wheat cross, 'Henry' x 'Lemhi', Chapman and McNeal (10) reported high-parent heterosis levels of 34 and 6% for yield for 1967 and 1968, respectively. The F_2 hybrid was 29% higher in yield than its high-parent in 1967 but similar to its midparent in 1968. The performance of the F_2 was 96% of the F_1 in 1967 and 85% in 1968, indicating an inbreeding depression for yield of 4 and 15% in 1967 and 1968, respectively.

From the comparison between the F_1 and the F_2 generation, Bitzer and Fu (4) reported inbreeding depression values of 14, 4, 7, and 8% for grain yield, number of spikes, kernels/spike and kernel weight, respectively. They concluded that any heterotic effect that existed in the F_1 was generally lost in the F_2.

Diallel Analysis: General and Specific Combining Ability

The modern use of combining ability analysis starts apparently with the development of the concept of general and specific combining ability as described by Sprague and Tatum (45). They partitioned the genotypic variance into general and specific combining ability portions and defined the term 'general combining ability' as the average performance of a line in a series of hybrid combinations, and 'specific combining ability' as the performance of certain combinations that do relatively better or worse than would be expected on the basis of the average performance of the lines involved.

The diallel analysis has been widely used to estimate general and specifc combining ability in a number of species. Also it has been used to some extent to investigate the nature of gene action. Griffing (16) described four experimental methods and presented numerical examples of a diallel cross for studies of combining ability using F_1 progeny with or without reciprocals and parental lines. Schaffer and Usanis (39) recently developed a computer program, 'Diall', which provides a least squares analysis for a general (unbalanced) diallel experiment. Kempthorne and Curnow (25) presented genetic formulae for general and specific combining ability as: (a) variance of general combining ability,

$$(\sigma^2 g) = \frac{1}{2}\sigma^2 A + \frac{1}{4}\sigma^2 AA + \cdots$$

and (b) variance of specific combining ability,

$$(\sigma^2 s) = \sigma^2 D + \frac{1}{2}\sigma^2 AA + \sigma^2 AD + \sigma^2 DD + \cdots \quad .$$

They pointed out that general combining ability variance is due primarily to additive genetic variance while specific combining ability variance estimates primarily non-additive genetic variance. Rojas and Sprague (37) found in maize that the specific combining ability variance included not only the non-additive variation due to dominance and epistasis, but also a considerable portion of the genotype x environment interaction. They also found that the specific combining ability variance became of relatively greater importance than the general combining ability variance when the lines under test had been subjected to previous selection for general combining ability.

Vanderberg and Matzinger (47) estimated combining ability in a diallel cross involving ten tobacco lines at two locations following the procedure of Matzinger and Kempthorne (31). Significant general combining ability variances were observed for all traits studied while specific combining ability variances were significant for five of nine characters evaluated. They observed considerable general combining ability by location interaction effects for flowering, height, leaf length, and leaf width.

Matzinger, et al. (32) studied combining ability in the F_1 and F_2 generations of a diallel cross of eight burley tobacco varieties. They reported the presence of an appreciable amount of variance due to general combining ability and the absence of variance due to specific combining ability for all characters studied in both generations, indicating that practically all of the genetic variance resulted from additive effects of genes, with essentially no dominance or epistatic variance.

Leffel and Weiss (29) used Griffing's (16) method of analysis to estimate general and specific combining ability variances and general combining ability effects for yield and other important agronomic characteristics in F_1 populations derived from a 10-parent diallel cross of soybeans. While both general and specific combining ability were of importance for yield, date of flowering, plant height, and seed quality, general combining ability variances were much greater than specific combining ability variances for maturity, flowering, and seed size. In a later study which involved F_2 and F_3 bulk populations as well as F_3 lines grown at different locations and in different years, Leffel and Hanson (28) estimated general and specific combining ability variances and components due to environmental interactions by an analysis described by Rojas and Sprague (37). They found general combining ability to be especially prominent for seed yield, seed size, and maturity. For plant height and maturity, relatively large specific combining ability effects were observed. The magnitude of general combining ability by environment interactions, and specific combining ability by environment interactions were generally small and statistically significant in only a few instances.

Weber, et al. (49) estimated combining ability in a diallel study of 10 F_1 hybrids derived from crosses involving five soybean varieties. They reported that both general and specific combining ability variances were significant for seed yield, maturity date and plant height. Except for oil content, general combining ability variances were two to six times larger than specific combining ability.

Estimates of general and specific combining ability effects were obtained by Niehaus and Pickett (36) in an eight-parent diallel study of inbred sorghum lines. The F_1 and F_2 generations were included in the analysis. Significant general and specific combining ability variances were observed for all of the eight traits evaluated in the F_1 generation. In the F_1's general combining ability variances were larger than specific combining ability variances in all cases except for seed weight. They concluded that there was considerable non-additive gene action involved in the expression of characters in the F_1 generation, much of which was lost in the F_2 generation.

Components of variance estimates for general and specific combining ability and their interaction with years were determined from 190 grain sorghum hybrids produced by crossing 10 male-sterile lines with 19 fertility restoring lines by Kambal and Webster (24). They found general combining ability to be considerably more important and more stable over years than specific combining ability for yield, seed weight, test weight, plant height and days to bloom.

Beil and Atkins (3) studied combining ability in F_1 grain sorghum hybrids at two locations for two years. Significant general combining ability variances were observed for yield, heads per plant and seed weight, while specific combining ability was significant only for seed weight. The component for general combining ability was nearly three times larger than that for specific combining ability for these traits. They also found that specific combining ability for grain yield was more stable than general combining ability over the four environments.

Muehlbauer, _et al_. (35) studied combining ability in the F_1, F_2, and F_3 generations of reciprocal crosses involving six winter and spring oat varieties for several important agronomic characteristics. They found that general combining ability was a major component of variation for maturity, plant height, straw length, and yield in all generations while specific combining ability was important for plant height and tiller number in the F_1, but generally was not important in the F_2 and F_3 for maturity, plant height, straw strength, and yield.

Upodhyaya and Rasmusson (46) estimated combining ability in a diallel study of eight barley varieties grown in two environments. They found that general combining ability variances to be more important than specific combining ability variances for number of kernels per head, and plant height. The specific combining ability variance, however, was larger than general combining ability variance for yield, indicating that non-additive genetic variance was more important for this trait.

Estimates of general and specific combining ability effects were obtained by Kronstad and Foote (26) in a diallel study involving 10 winter wheat varieties. They found that a large part of the total genetic variation for yield and yield components was associated with general combining ability. Significant specific combining ability variances were observed for plant yield and height but not for yield components.

Estimates of relative magnitudes of general and specific combining ability were obtained by Brown, et al. (9) in a diallel study of 10 F_1 hybrids derived from crosses involving three hard and two soft winter wheat varieties. They found that general combining ability variances were highly significant and more important than specific combining ability for yield, kernel weight, and spike number. Specific combining ability was not significant for any of these traits.

Gyawali, et al. (17) found general combining ability to be the major component of genetic variation for important agronomic and quality characteristics in a study of winter wheat crosses, although specific combining ability variances were significant for all traits studied except flour yield and micro-alkaline water retention capacity. They found that specific combining ability was more important than reported by other workers (9,26) and believed this to be due to selection of experimental material.

McIlrath, et al. (33) found highly significant general and specific combining ability variances for all characters measured in the F_1 of a diallel cross of wheat varieties. General combining ability variances, however, were well in excess of specific combining ability variances for all traits including yield, indicating that the genetic variability in the hybrids was predominantly due to additive effects of genes.

Walton (48) estimated general and specific combining ability effects in two different diallel crosses of spring wheat. In both diallel systems, general combining ability variances were important for yield and yield components. Specific combining ability variances were significant for yield and yield components in one system but not the other.

Bitzer and Fu (4) found general combining ability to be the major component of genetic variation for six agronomic and three quality traits in a diallel study of six winter wheat varieties. Significant specific combining ability variances were obtained for heading date and flour yield but not for yield or yield components. These results along with those reported by other workers in winter wheat (9,17,26,33) and in spring wheat (48) lead to the conclusion that additive genetic effects account for most of the total genetic variability in wheat for important agronomic characters.

Predictive Values

The value of early generation testing in self-pollinated crops has not been completely established. Several studies have indicated the reliability of using early generation testing as well as parental performance in predicting the potential value of bulk populations. Conversely, other studies under similar conditions have indicated that the predictive value of tests in early generations is of little or no value in identifying superior crosses.

In one wheat cross, 'Marquis' x 'Marquillo', Harrington (18) found that the classification of several hundred single F_2 plants correctly predicted the value of the progeny as to earliness, height, stem rust reaction, and seed characters. The yields of individual F_2 plants, however, were somewhat misleading and proved to be of little value in predicting the yielding capacity of their progeny. Later, Harrington (19) conducted replicated yield trials of wheat crosses in F_2 and F_3

generations. The yielding value of certain crosses was determined later by replicated yield tests of selected lines in the F_6, F_7, and F_8 generations. He concluded that replicated bulk F_2 tests could be used to indicate the yielding potentialities of segregates for these crosses. Bulk F_3 yield trials were considered of supplementary value.

In a study of six barley crosses, Immer (21) reported that yielding potentiality of different crosses could be determined by means of replicated yield trials in the F_2 or F_3 generation. It was concluded that low-yielding crosses in the F_2 or F_3 generation could be safely discarded since the portion of high yielding genotypes in low-yielding crosses would be much lower than in crosses with a high average yield.

A ten-parent diallel cross of soybeans was studied in the F_1, F_2 spaced, F_2 bulk, F_3 bulk, and F_3 line generations by Leffel and Hanson (28). The performance of randomly selected F_3 lines were used as the criterion to determine the value of a cross. Correlation coefficients indicated that all generations, with the possible exception of the F_1, were of value in predicting the value of crosses. Also, the performance of the parents themselves was reliable in identifying superior crosses.

Atkins and Murphy (1) studied early-generation bulked progenies of 10 oat crosses and compared the performance of early generations with 50 pure line segregates from each cross. They found that bulk populations which gave the highest yields in replicated trials in the early segregating generations did not produce the greatest portion of high-yielding segregates in subsequent generations. The two crosses from which the greatest portion of superior segregates were derived had been classified as potentially poor yielders and might have been discarded in a breeding program. Correlations between successive generations of bulk hybrids for yield were consistently low indicating that predictions of yield performance of bulk hybrids from their performance in previous generations appeared to be of limited value. They observed high genotype by environment interactions for yield and stated that the yield potentialities of a cross could not be reliably predicted on the basis of single performance tests in early generations.

Fowler and Heyne (13) tested 45 wheat crosses from F_2 through the F_5 generation. They noted large differential responses from generation to generation and from year to year and concluded that early-generation bulk hybrid tests were of no value in identifying superior crosses. They also found that parental performance was of limited value in predicting the potential value of bulk populations.

Smith and Lambert (44) examined the value of predictions based on early-generation performance in spring barley. The predictive value with respect to yield and kernel weight of the parents and early-generation bulks of a six-parent diallel cross was determined by the performance of F_5 lines derived from the crosses. They found that predictions for yield and kernel weight based on the performance of parents and early-generation bulk hybrids as well as those derived midparent and parental array values were generally useful and reliable in identifying potentially valuable crosses.

CHAPTER III

MATERIALS AND METHODS

Materials

Two different diallel crossing systems were studied. The first system consisted of seven varieties and pure-line experimental selections of hard red winter wheat (*Triticum aestivum* L. em Thell) and their single cross progenies. Hybrid progenies of this system were studied in the F_1 and F_2 generations in 1969. The second diallel crossing system consisted of a six-parent diallel cross. The F_2 and F_3 generations of this system were studied in 1970 and 1971.

Seven-Parent Diallel Test of F_1's and F_2's -- 1969

The seven parents and all the possible 21 F_1 and F_2 hybrids comprised the basic genetic material for these studies. All possible single crosses, disregarding reciprocals, among the seven parents were made in the greenhouse in 1967 by the approach method of crossing. The 21 F_2 hybrids resulted from a diallel crossing system of the same seven lines which had been studied previously (27). The seven parents used for crossing were chosen to represent a range in genetic diversity for major agronomic characteristics. The pedigree and a brief description of the characteristics of the parents are given in Table I. In subsequent sections of this report the varieties will be referred to by their abbreviation as shown in this table.

TABLE I

PARENTAGE, ORIGIN AND AGRONOMIC CHARACTERISTICS OF THE PARENTS USED IN A SEVEN-PARENT DIALLEL CROSS

Variety or Selection	Abbreviation	C. I. or Selection No.	Agronomic Characteristics	Origin	Parentage
Scout	Sut	13546	high yield wide adaptation mid-maturity	Nebraska	Nebred, Hope, Turkey, Cheyenne, Ponca
Triumph 64	Tmp 64	13679	high yield wide adaption early maturity	Oklahoma	Triumph, Danne Beardless, Kanred, Blackhull, Florence
Agent	Ag	13523	leaf rust resistant stiff straw mid-late maturity	Oklahoma	Triumph, *Agropyron elongatum*, *Triticum* spp.
3*Kaw//DS28A/Pnc	7654	OK657654	greenbug resistant (race A) mid-maturity	Oklahoma	Kaw, Dickinson Selection 28A, Ponca
Sturdy	Sdy	13684	semi-dwarf good quality mid-maturity	Texas	Sinvalocho, Wichita, Hope, Cheyenne, Seu Seun 27
Comanche	Cmn	11673	good quality mid-maturity	Kansas	Oro, Tenmarq
Danne	Danne	13876	high yield good quality early maturity	Oklahoma	Triumph, Danne Beardless, Blackhull, Kanred, Florence

Detailed descriptions of Scout, Triumph 64, Agent, Sturdy, Comanche, and Danne have been published (2,8,23,40,42,43). The other parent (OK657654) is an experimental strain developed at the Oklahoma Agricultural Experiment Station. It is a selection from the cross of 3*Kaw//DS28A/Ponca and was first tested in the BCF_3 generation in 1965. The selection carries the DS28A gene which confers resistance to race A of the greenbug (Schizaphis Graminum Rond.). Recently, a new dominant strain of the greenbug has been found in Oklahoma wheat fields. OK657654 is resistant to the original strain (race A) but is susceptible to the new strain (race B) (51). OK657654 is similar to Kaw 61 in maturity, height and yield. However, it is not as winterhardy as Kaw 61.

Six-Parent Diallel Test of F_2's and F_3's -- 1970 and 1971

This material consisted of the bulk hybrid progenies of 15 single crosses resulting from all possible combinations among six parental lines. The six parents and their single cross progenies were a part of the original seven-parent diallel crossing system. The parent Danne and its corresponding hybrids were omitted because this variety, in several hybrid combinations, resulted in necrotic symptoms. The six parents chosen as source material for this study were therefore: Scout, Triumph 64, Agent, OK657654, Sturdy, and Comanche. Seed produced on F_1 and F_2 plants from the previously described seven-parent diallel system was used for planting the F_2 and F_3 hybrids, respectively.

Experimental Methods

Seven-Parent Diallel Test of F_1's and F_2's -- 1969

A total of 49 entries consisting of the seven parents, 21 F_1 hybrids, and 21 F_2 hybrids were seeded on October 25, 1968 in hill-plots arranged in 7 x 7 complete lattice design with eight replications at the Agronomy Research Station, Stillwater, Oklahoma. The soil type was an eroded Norge loam with a 4 to 6% slope. Plots consisted of one row containing four hills with 30 cm spacing between hills and between rows. Each hil contained three seeds and comprised a sub-plot. The experiment was bordered by hill-plots of the variety Goldenchief to provide uniform competitive conditions for all plots. The material was harvested by pulling all the plants in each hill at maturity. The spikes were bagged to prevent seed loss during storage.

Six-Parent Diallel Test of F_2's and F_3's -- 1970 and 1971

Entries consisted of 15 F_2 bulk hybrids, 15 F_3 bulk hybrids, and six parents. The experiment was arranged in a 6 x 6 lattice design with six replications at the Agronomy Research Station, Stillwater, Oklahoma. The 1970 test was seeded on October 21, 1969 on a Norge loam (1-3% slope) soil. The 1971 test was seeded on October 25, 1970 on a Renfrom soil type. Plots were planted to a solid stand (24 seeds per 30 cm of row). Each plot was 3 m long and consisted of two rows 30 cm apart. Both rows were trimmed back to 2.5 m prior to harvest for yield determinations.

Characters Evaluated

Seven-Parent Diallel Test of F_1's and F_2's -- 1969

The characters studied were: (1) heading date, (2) plant height, (3) spike number, (4) kernel weight, (5) kernels/spike, and (6) grain yield. All observations were recorded on a per hill basis.

Heading Date. Heading date, used as a measure of relative maturity, was recorded as the number of days from April 1 until the first spike in each hill-plot was completely emerged from the boot.

Plant Height. Measurements were taken in centimeters from the soil surface to the tip of the tallest spike of each hill, exclusive of awns.

Spike Number. This character was determined by a direct count of the number of tillers in each hill bearing fertile spikes, and was expressed as number of spikes per hill.

Kernel Weight. This was determined by weighing 200 random kernels from each sub-plot to the nearest 1/10 of a gram. Kernel weight was expressed as grams per 200 kernels.

Kernels/Spike. This was calculated by the following formula:

$$\frac{\text{grain yield (in grams)} \div \text{average weight per kernel}}{\text{total number of spikes per hill}}$$

and was expressed as average number of kernels per spike.

Grain Yield. Grain yield determinations consisted of the weight of the threshed, cleaned seed from each hill expressed in grams per hill.

Six-Parent Diallel Test of F_2's and F_3's -- 1970 and 1971

The characters evaluated were: (1) heading date, (2) plant height, (3) spike number, (4) kernel weight, and (5) grain yield. All observations were recorded on a per plot basis.

Heading Date. Heading date, used as a measure of maturity was recorded as the number of days from April 1 until when the 75% of the heads in the plot were completely out of the boot.

Plant Height. This was measured in centimeters from the soil surface to the top of a handful of spikes exclusive of awns. The measurement represented the average of two independent readings per plot.

Spike Number. This was presented as the number of seed-bearing tillers in a 30 cm section of each of the two rows comprising the plot. The value represent the average of these two independent counts.

Kernel Weight. This was determined by weighing 200 random kernels from each plot to the nearest 1/10 of a gram. Weights were expressed in grams per 200 kernels.

Grain Yield. Grain yield was obtained by weighing the threshed and cleaned seed from each plot. This was expressed as grams per plot.

Statistical Analyses

The lattice analysis of the seven-parent diallel test in 1969 showed no appreciable gain in efficiency over a randomized block design for any of the six characters. Therefore, for each generation, all characters measured in this test were analyzed as randomized blocks.

The lattice analysis for kernel weight in the six-parent diallel test in 1970 resulted in 43% more efficiency than the randomized block analysis but none of the other characters studied showed any appreciable gain in efficiency. The lattice analysis for yield in the 1971 test resulted in 26% more efficiency than the randomized block analysis but none of the other characters showed any appreciable gain in efficiency in this test. Since the efficiency of lattice design was quite variable between the characters tested in the same year or the same character tested in different years, the six-parent diallel tests grown in 1970 and 1971 were analyzed finally as randomized complete block designs for all characters measured.

A combined analysis of variance (1 location, 2 years) was conducted on the data from the six-parent diallel test grown in 1970 and 1971 for the following traits: spike number, kernel weight, and grain yield.

Associations between generations were studied by simple correlations for all characters as method of predicting potential value of a cross in early generations.

Heterosis Analysis

Heterosis was measured for all F_1, F_2, and F_3 populations in relation to both the midparent and the high-parent values. Since hybrid means were based on only half as many observations as midparent values, adjusted LSD values were used to test each hybrid-midparent contrast. The standard deviation of a hybrid-midparent contrast was defined as: Sd for hybrid vs midparent = $\sqrt{3EMS/2r}$ where EMS is the experimental error mean square and r represents the number of observations comprising the treatment mean (34). The LSD values were calculated as follows:

LSD = SD $t_{(\alpha,t-1)}$. Duncan's new multiple range test was used to determine the significance of differences among means of hybrids and parents.

Inbreeding depression was considered to be the degree of reduction of the F_2 performance below that of the F_1. Duncan's new multiple range test was used to test the significance of inbreeding depression of the F_2 hybrids with respect to their corresponding F_1 hybrids.

Combining Ability Analysis

All diallel tests (F_1's through F_3's) were subjected to combining ability analyses using model 1, method 4 of Griffing (16), which excludes the parents and reciprocal crosses. Under this model the genotypes and blocks are regarded as fixed effects. The use of this model prohibits any inferences being made to a larger population since the experimental material was not a random sample of any population. Griffing's analysis provides for partitioning the sum of squares of genotype (crosses) into general and specific combining ability terms associated with p-1 and p(p-3)/2 degrees of freedom, respectively, where p represents the number of parents involved in the diallel cross.

General and specific combining ability effects were computed on the Oklahoma State University Computing Center IBM 360/65. Diallel analyses of the F_2 and F_3 bulk hybrids were also conducted on combined years on the Oklahoma State University Computing Center IBM 360/65 using a program developed at the North Carolina State University (39).

CHAPTER IV

EXPERIMENTAL RESULTS

General Considerations

Growing conditions throughout the extent of these experiments were generally favorable except for the 1971 test. Some soil moisture stress was encountered prior to heading in the 1971 test and this resulted in restricted plant growth, and earlier-than-normal heading. Heading date and plant height measurements were not made for this reason. The mean yields of all entries grown in connection with the tests are presented to provide a general picture of the growing conditions encountered during the study. Average grain yield in the 1969 test was 26.7 grams per hill (42 bushels per acre). The test mean yields were 380 and 350 grams per plot (approximately 38 and 35 bushels per acre) for 1970 and 1971, respectively. There were no problems with diseases or insects and no winter killing or lodging occurred. However, in the 1969 test severe leaf injury was observed in three hybrids, Sut/7654, Sut/Danne, and Ag/Danne, apparently due to hybrid necrosis as described by Hermsen (20). This hybrid necrosis no doubt had an adverse effect on yield and yield components of these three hybrids as indicated by the negative heterosis that was observed for yield and yield components.

Heterosis and Inbreeding Depression

Seven-Parent Diallel Test of F_1's and F_2's -- 1969

The analysis of variance of six agronomic characters on 21 F_1 hybrids, 21 F_2 hybrids and seven parents showed highly significant differences among genotypes for all characters (Appendix Table XVII). Parent and hybrid means for the six traits, along with appropriate tests for significance are given in Appendix Tables XVIII-XXIII. The performance of the hybrids in relation to their respective high-parent and midparent values are presented in Table II. As a measure of inbreeding depression, each F_2 hybrid is expressed in percent of its respective F_1 value. This information is shown in Table III.

Heading Date. In general, the F_1 hybrids were earlier than the late parent but slightly later than the earlier parent. No F_1 hybrid headed significantly earlier than its early parent. However, significant midparent heterosis for earliness was observed in seven F_1 hybrids (Table II). Six of these seven F_1's also showed significant midparent heterosis for yield. Ten F_1 hybrids headed significantly later than their respective earlier parents and two F_1's were significantly later than their midparents (Appendix Table XVIII).

Thirteen of 21 F_2 hybrids were significantly earlier than their midparents. All of the hybrids which showed significant midparent heterosis for earliness in the F_1 were also significantly earlier than their respective midparents in the F_2 generation. Sixteen F_2 hybrids headed earlier than their corresponding F_1 hybrids and eight of them were significantly earlier (Table III).

TABLE II

PERFORMANCE OF F_1 AND F_2 HYBRIDS EXPRESSED AS PERCENT OF HIGH-PARENT AND MIDPARENT MEANS FOR SIX CHARACTERS FROM SEVEN-PARENT DIALLEL CROSS, 1969

Hybrid	Heading Date				Plant Height				Spike Number			
	%HP[1]		%MP		%HP[2]		%MP		%HP[3]		%MP[4]	
	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
Sut/Tmp 64	91	88	96**	93**	100	105	100	105	100	96	102	97
Sut/Ag	95	94	100	99	105	100	109**	104	106	94	107	96
Sut/7654	103	98	107**	102	105	106	105*	106**	109	98	110*	100
Sut/Sdy	92	90	96**	93**	94	95	106*	108**	96	89	102	94
Sut/Cmn	98	98	101	101	101	105*	105*	109**	110	100	111*	101
Sut/Danne	95	91	101	95**	96	103	98	105*	80*	97	83**	101
Tmp 64/Ag	85	83	94**	92**	97	96	100	100	98	88	101	91
Tmp 64/7654	97	92	99	93**	100	103	101	104	104	98	107	100
Tmp 64/Sdy	98	96	99	97**	91	92	103	105	87*	83*	94	89*
Tmp 64/Cmn	88	87	95**	95**	93	99	97	103	104	92	105	93
Tmp 64/Danne	101	102	101	102	99	97	102	99	95	92	100	97
Ag/7654	95	91	104	99	105*	103	109**	106**	117*	104	118*	105
Ag/Sdy	83	82	91**	90**	92	93	108**	108**	97	92	102	96
Ag/Cmn	97	97	99	99	104*	103	105*	103	109	98	111*	100
Ag/Danne	89	87	98	96**	97	96	102	102	99	92	101	94
7654/Sdy	98	99	99	100	94	102	107**	117**	93	100	97	104
7654/Cmn	97	91	104**	97**	108*	99	112**	102	100	95	102	97
7654/Danne	99	94	101	96**	99	104	102	106**	99	95	101	97
Sdy/Cmn	88	84	95**	90**	87	94	102	110**	96	93	103	99
Sdy/Danne	98	96	99	97	96	103	107**	115**	103	99	105	101
Cmn/Danne	88	89	95**	96**	95	100	101	106**	106	97	110*	101
MEAN	94	92	99	96	98	100	104	106	100	95	103	98

TABLE II (Continued)

Hybrid	Kernel Weight				Kernels/Spike				Grain Yield			
	%HP		%MP		%HP		%MP		%HP		%MP	
	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
Sut/Tmp 64	109*	92*	114**	97	92	112*	93	113**	100	100	107	106
Sut/Ag	111*	101	118**	109**	91*	88*	102	99	128*	100	133**	104
Sut/7654	96	93*	96	93**	85*	96	89**	101	92	92	95	94
Sut/Sdy	110*	104	115**	109**	89*	91	98	100	114	101	116*	103
Sut/Cmn	103	86*	110**	91**	92	117*	95	120**	113	108	116*	112
Sut/Danne	95	103	97	105*	96	91	103	97	78*	98	83**	103
Tmp 64/Ag	107*	95	121**	107**	82*	82*	96	96	116	93	119**	95
Tmp 64/7654	102	92*	108**	97	94	100	100	106	112	97	116**	101
Tmp 64/Sdy	101	91*	111**	100	93	99	102	109**	100	91	108	98
Tmp 64/Cmn	104	94*	115**	104	98	99	102	103	114	92	125**	100
Tmp 64/Danne	100	90*	103	93*	96	101	104	109**	106	97	107	98
Ag/7654	107*	96	114**	103	97	97	104	104	140*	111	141**	112*
Ag/Sdy	122*	106	124**	109**	97	101	99	103	119*	103	126**	108
Ag/Cmn	121*	91*	122**	92**	95	107*	104	117**	133*	101	141**	108
Ag/Danne	87*	85*	95	92*	104	105	109**	110**	103	96	105	97
7654/Sdy	112*	99	117**	104	97	95	102	99	111	103	116*	107
7654/Cmn	95	97	100	103	101	95	103	98	101	92	106	97
7654/Danne	95	101	97	104*	105	99	107*	101	102	101	105	103
Sdy/Cmn	118*	113*	119**	115*	94	97	101	103	123*	116	125**	118**
Sdy/Danne	108	98	115**	104	98	98	100	100	115	99	123**	106
Cmn/Danne	102	91*	110**	99	100	115*	104	120**	119*	110	128**	119**
MEAN	105	96	111	101	95	99	101	105	111	100	116	104

[1] HP = later parent.

[2] HP = taller parent.

[3] %HP = percent of high parent.

[4] %MP = percent of midparent.

Note: Significantly (*) or highly significantly (**) different than its high parent or its midparent based on LSD.

TABLE III

PERFORMANCE OF F_2 HYBRIDS EXPRESSED AS PERCENT OF THEIR CORRESPONDING F_1 HYBRIDS FOR SIX CHARACTERS FROM SEVEN-PARENT DIALLEL CROSS, 1969

Hybrid	Heading Date	Plant Height	Spike Number	Kernel Weight	Kernels/Spike	Grain Yield
	F_2/F_1[1]	F_2/F_1	F_2/F_1	F_2/F_1	F_2/F_1	F_2/F_1
Sut/Tmp 64	96*	105	96	85*	122*	100
Sut/Ag	99	95	89	91*	97	78*
Sut/7654	95*	101	91	97	113*	100
Sut/Sdy	97	101	92	95	102	88
Sut/Cmn	101	104	91	83*	127*	96
Sut/Danne	95*	106*	122*	108*	94	124*
Tmp 64/Ag	97	100	91	89*	99	80*
Tmp 64/7654	95*	103	93	90*	106	87
Tmp 64/Sdy	98	101	95	91*	106	91
Tmp 64/Cmn	99	106	89	90*	101	81*
Tmp 64/Danne	101	97	97	91*	105	92
Ag/7654	96*	98	89	90*	100	79*
Ag/Sdy	98	101	95	88*	104	86
Ag/Cmn	100	99	90	75*	112*	76*
Ag/Danne	98	100	93	97	101	92
7654/Sdy	100	109*	96	89*	98	93
7654/Cmn	93*	91*	95	103	95	91
7654/Danne	95*	104	96	107*	94	99
Sdy/Cmn	95*	108*	96	96	103	94
Sdy/Danne	98	107*	96	91*	98	86
Cmn/Danne	101	104	91	89*	115*	92
MEAN	98	102	90	92	105	91

[1] F_2/F_1 = performance of F_2 as percent of F_1.

Note: Significantly (*) different than its F_1 hybrid based on Duncan's multiple range test.

Plant Height. The mean value of both the F_1 and F_2 hybrids for plant height ranged from values 15.5 cm taller than the shortest parent, Sdy, to values 10 cm taller than the tallest parent, Cmn, but most of the hybrids were within 10 cm of their midparent values for this trait. Six F_1 hybrids exceeded their high parents in mean plant height, although only three hybrids were significantly taller (Table II). Two of these three hybrids, Ag/7654 and Ag/Cmn, were the highest yielding entries in the test. Significant positive midparent heterosis for plant height was observed in 10 F_1 hybrids, seven of which also showed significant midparent heterosis for yield.

Ten F_2 hybrids exceeded their respective high parents in mean plant height, although only one hybrid was significantly greater. Seven of the 10 F_1 hybrids which exhibited significant midparent heterosis for plant height were also significantly taller than their respective midparents as F_2.

Spike Number. Nine F_1 hybrids exceeded their respective high parents for this trait although only one hybrid, Ag/7654, was significantly greater (Table II). This hybrid also had the greatest number of spikes and was the highest yielding entry in the test. The Sut/Danne hybrid was significantly lower than its midparent value. The very low spike number of this hybrid apparently resulted from hybrid necrosis. Significant midparent heterosis for spike number, however, occurred in five F_1 hybrids; four of which also showed significant midparent heterosis for yield (Table II). The mean for all F_1's for this trait was 100 and 103% of the high-parent and midparent values, respectively.

In general, the F_2 hybrids had a slightly lower (5%) spike number than their respective high parents but approached closely the level of their midparent value. One F_2 hybrid, Tmp 64/Sdy, had significantly fewer spikes than its midparent.

The F_2 hybrids had a lower spike number than their corresponding F_1 hybrids, averaging considerably less than their respective F_1 hybrids (Table III). There was one notable exception. The Sut/Danne F_2 hybrid was significantly greater than its corresponding F_1 counterpart. However, this effect was, no doubt, due to the severe necrosis exhibited in the F_1. In many cases, greater inbreeding depression in the F_2 was observed for those hybrids which exhibited a higher degree of heterosis for this trait in the F_1. The largest inbreeding depression (11%) occurred in the Ag/7654 F_2 hybrid which showed the largest high-parent heterosis for this trait in the F_1 (Tables II and III). The mean for all F_2's was 90% of the average of all F_1's indicating that average inbreeding depression for spike number was 10%.

Kernel Weight. Fifteen F_1 hybrids were higher than their respective high parents in kernel weight, although only nine hybrids showed statistical significance. Five of these nine hybrids also showed significant high-parent heterosis for yield (Table II). Most of the hybrids that exceeded their high parents in yield also exceeded their high parents for this trait. The heaviest kernel weight was found in the Sut/Tmp 64 F_1 hybrid while the largest high-parent heterosis was observed in the Ag/Sdy F_1 hybrid (Table II). Significant positive midparent heterosis for kernel weight occurred in 15 F_1 hybrids, 13 of which also showed significant positive midparent heterosis for yield (Table II). The mean for all F_1's for this trait was 105 and 111% of the high-parent and midparent values, respectively.

In general, the F_2 hybrids were slightly lower (4%) in kernel weight than their high parents but were essentially similar to their midparents. Six F_2 hybrids exceeded their respective high parents for kernel weight although only one hybrid, Sdy/Cmn, was statistically significant. Five F_2 hybrids were significantly lower than their respective midparents for this trait. Significant positive midparent deviations for kernel weight occurred in seven F_2 hybrids. Five of these seven F_2 hybrids also exhibited significant midparent heterosis for this trait as F_1 (Table II).

The overall magnitude and direction of inbreeding depression for this trait was somewhat similar to that found for spike number. Thirteen of 15 F_1 hybrids which showed significant midparent heterosis for kernel weight exhibited significant inbreeding depression in the F_2. The degree of inbreeding depression, in most cases, was related to the degree of heterosis exhibited by F_1 hybrids. The largest inbreeding depression (25%) occurred in the Ag/Cmn F_2 hybrid which showed the largest high-parent heterosis for this trait as F_1 (Tables II and III). Inbreeding depression for kernel weight averaged 8% for the 21 hybrids.

Kernels/Spike. As a group, the F_1 hybrids were slightly lower (5%) in kernels/spike than the high-parent mean but approached closely the level of the midparent value. No F_1 hybrid was significantly higher in kernels/spike than its high-parent. However, two F_1 hybrids showed significant midparent heterosis for this trait (Table II). The Ag/Danne hybrid had the greatest kernels/spike in the F_1 generation which is interesting since this hybrid exhibited necrotic symptoms. Four hybrids were significantly lower in kernels/spike than their respective high parents. The Sut/7654 hybrid was also significantly lower than its midparent. This hybrid was also beset with necrosis.

In general, the F_2 hybrids were slightly higher (5%) than the midparent but similar to the high-parent value. Seven F_2 hybrids exceeded their respective high parents in kernels/spike, although only four hybrids were significantly so (Table II). Seven F_2 hybrids showed significant positive midparent deviations for this trait. The greatest kernels/spike in the F_2 generation occurred in the Ag/Cmn hybrid while the largest positive high-parent deviation was found in the Sut/Cmn hybrid.

Estimates of inbreeding depression for kernels/spike were different in magnitude and direction from that found in the two other yield components. All but eight F_2 hybrids produced more kernels/spike than their corresponding F_1 hybrids which resulted in a 5% mean increase of the F_2's over the F_1's (Table III). Five F_2 hybrids were significantly higher in kernels/spike than their corresponding F_1 counterparts. The Sut/Cmn F_2 hybrid was 27% better than its F_1 counterpart. Eight F_2 hybrids were lower than their corresponding F_1 counterparts, however, none of these differences were statistically significant (Table III). The largest inbreeding depression occurred in the Sut/Danne hybrid and the 7654/Danne hybrid, both of which were 6% lower than their respective F_1 counterparts.

Grain Yield. Estimates of heterosis for yield were higher than that of the individual components of yield. Nineteen of 21 F_1's were higher than their respective high parents, and six hybrids, Ag/7654, Ag/Cmn, Sut/Ag, Cmn/Danne, Ag/Sdy, and Sdy/Cmn, were significantly higher than their high parents. Five of these six hybrids also showed significant high-parent heterosis for kernel weight (Table II). The greatest high-parent heterosis was observed in the Ag/7654 hybrid which was 40% better than its high-parent. This hybrid was also the highest yielding entry in the test (Appendix Table XXIII). Nineteen F_1 hybrids were higher than their respective midparents for yield and 13 of them were significantly better. All of these 13 hybrids also exhibited significant midparent heterosis for kernel weight. The lowest yielding hybrids in the F_1 generation were Sut/Danne and Sut/7654 which were also beset with hybrid necrosis. The Sut/Danne hybrid was significantly lower in grain yield than its high-parent and midparent. The range for grain yield of the 21 F_1 hybrids was 78 to 140% of the high-parent values and 83 to 141% of the midparent values. The mean for all F_1's was 111% and 116% of the high-parent and midparent values, respectively (Table II).

As a group, the F_2 hybrids were slightly higher (4%) than their midparent values and approached the level of the high-parent value. Most of the F_1's that exceeded their midparent for yield also exceeded their midparent for yield as F_2. Nine F_2 hybrids were higher than their respective high parents and 14 F_2 hybrids were higher than their respective midparents for yield. However, only three F_2's, Ag/7654, Sdy/Cmn, and Cmn/Danne, showed significant midparent deviations. The largest positive high-parent deviation in the F_2 generation occurred in the Sdy/Cmn hybrid while the highest yielding F_2 in the test was the Cmn/Danne hybrid. The lowest yielding F_2 hybrid was Sut/7654, which was also affected by necrosis. No F_2 hybrid was significantly lower in grain yield than its high-parent or midparent (Table II).

The degree of inbreeding depression for grain yield was related to the amount of heterosis exhibited by the F_1 hybrids. Those F_1's which displayed higher levels of heterosis in yield tended to show greater inbreeding depression in the F_2 generation. Significant inbreeding depression occured in the Ag/Cmn, Sut/Ag, Ag/7654, Tmp 64/Ag, and Tmp 64/Cmn F_2

hybrids which were 24%, 22%, 21%, 20%, and 19% lower than their corresponding F_1 counterparts, respectively (Table III). These five hybrids were also among the top six highest yielding entries as F_1 hybrids in the test. The Sut/Danne was the only F_2 hybrid which yielded higher than its corresponding F_1 counterpart. This was probably due to severe hybrid necrosis which occurred in the F_1. The mean for all F_2's was 91% of the average of F_1 value indicating that the average inbreeding depression for grain yield was 9%.

Performance of Early-Generation Bulk Hybrids

Six-Parent Diallel Test of F_2's and F_3's -- 1970 and 1971

An analysis of these generations was conducted separately for each year as well as a combined analysis over the two years. There were highly significant differences among genotypes for all characters in the analysis of variance over years. Also, highly significant year by genotype interactions were found for all characters (Appendix Table XXIV). In 1970 and in 1971, the individual year analyses also revealed highly significant differences among genotypes for all traits measured (Appendix Tables XXV and XXVI). Parent and hybrid means for all characters measured, along with appropriate tests for significance are given in Appendix Tables XXVII-XXXIV. Means of all F_2's and F_3's for all characters expressed as the percentage of their respective high-parent and midparent means are shown in Tables IV and V.

Heading Date. Heading Date was recorded for the 1970 test only. In general, the hybrids were earlier than the late parent but later than the earlier parent. The mean heading date of both F_2 and F_3 hybrids were

TABLE IV

PERFORMANCE OF F_2 AND F_3 HYBRIDS EXPRESSED AS PERCENT OF HIGH-PARENT AND MIDPARENT MEANS FOR FIVE CHARACTERS FROM SIX-PARENT DIALLEL CROSS, 1970

Hybrid	Heading Date				Plant Height			
	%HP[1]		%MP		%HP[2]		%MP	
	F_2	F_3	F_2	F_3	F_2	F_3	F_2	F_3
Sut/Tmp 64	97	95	101	99	100	100	101	101
Sut/Ag	97	94	102	99	101	99	102*	100
Sut/7654	102	99	103*	100	98	100	99	101
Sut/Sdy	97	100	97	100	99	98	109**	108**
Sut/Cmn	94	95	100	101	103	101	103**	101
Tmp 64/Ag	89	91	98	100	96	98	99	101
Tmp 64/7654	94	94	100	100	99	99	100	100
Tmp 64/Sdy	94	99	99	104*	102	102	110**	111**
Tmp 64/Cmn	86	87	96*	97	100	99	101	100
Ag/7654	97	98	101	102	98	99	100	101
Ag/Sdy	91	94	96*	99	95	96	106**	107**
Ag/Cmn	98	101	100	103	98	100	100	102
7654/Sdy	99	99	100	100	99	101	108**	110**
7654/Cmn	97	95	103	101	103	100	102	101
Sdy/Cmn	87	91	93**	97	100	101	110**	111**
MEAN	95	96	99	100	99	100	104	104

TABLE IV (Continued)

Hybrid	Spike Number				Kernel Weight				Grain Yield			
	%HP[3]		%MP[4]		%HP		%MP		%HP		%MP	
	F_2	F_3	F_2	F_3	F_2	F_3	F_2	F_3	F_2	F_3	F_2	F_3
Sut/Tmp 64	101	99	107	105	97	96	100	99	91	93	92	95
Sut/Ag	100	96	104	100	100	91	104	94	100	87	107	93
Sut/7654	86*	92	90*	96	97	100	103	106	89	88	100	99
Sut/Sdy	93	83	105	94	95	95	102	102	95	82*	105	90
Sut/Cmn	92	87	99	94	102	98	107	102	93	90	104	101
Tmp 64/Ag	94	96	95	98	94	97	101	103	91	90	96	95
Tmp 64/7654	112	97	114**	98	91	94	100	103	95	94	105	104
Tmp 64/Sdy	98	110	105	118**	98	90*	108*	95	107	91	115**	98
Tmp 64/Cmn	97	96	99	97	99	89*	106	96	90	90	99	99
Ag/7654	101	96	102	96	100	104	102	107	106	93	111	98
Ag/Sdy	92	88	100	95	98	101	102	105	86	86	89	89
Ag/Cmn	92	85*	95	87*	104	96	105	98	95	89	100	93
7654/Sdy	97	100	105	109	101	107	102	108*	108	105	111	108
7654/Cmn	100	96	103	98	101	96	103	98	104	103	104	103
Sdy/Cmn	107	94	112*	99	102	103	105	106	110	103	112	105
MEAN	97	94	102	99	99	97	103	102	97	92	103	98

[1]HP = later parent.

[2]HP = taller parent

[3]%HP = percent of high parent.

[4]%MP = percent of midparent.

Note: Significantly (*) or highly significantly (**) different than its high parent or its midparent based on LSD.

TABLE V

PERFORMANCE OF F_2 AND F_3 HYBRIDS EXPRESSED AS PERCENT OF HIGH-PARENT AND MIDPARENT MEANS FOR THREE CHARACTERS FROM SIX-PARENT DIALLEL CROSS, 1971

Hybrid	Spike Number				Kernel Weight				Grain Yield			
	%HP		%MP		%HP[1]		%MP[2]		%HP		%MP	
	F_2	F_3	F_2	F_3	F_2	F_3	F_2	F_3	F_2	F_3	F_2	F_3
Sut/Tmp 64	91	109	95	114	105	81	109**	100	107	109	113**	116**
Sut/Ag	87	91	89	93	98	94*	108**	104*	107	112	108	113**
Sut/7654	82	109	87	116	97	93*	103	99	108	108	111*	110*
Sut/Sdy	88	91	100	102	99	94*	105*	99	100	97	112*	109
Sut/Cmn	104	96	105	97	97	92*	100	96*	105	116*	106	117**
Tmp 64/Ag	105	86	106	87	100	99	109**	106**	97	91	103	97
Tmp 64/7654	90	100	91	102	103	91*	107**	94	104	102	107	105
Tmp 64/Sdy	90	94	98	102	96	99	99	102	100	94	106	101
Tmp 64/Cmn	87	84	91	88	105	106	105**	107**	102	97	109	103
Ag/7654	112	120	116	124**	100	95	104*	99	118*	98	122**	101
Ag/Sdy	92	103	101	113	103	96	108**	100	87	86	98	98
Ag/Cmn	96	85	100	88	99	95	105**	102	102	102	102	102
7654/Sdy	92	108	98	115	106*	100	106**	100	95	97	101	107
7654/Cmn	103	97	110	104	98	89*	101	91**	102	98	105	101
Sdy/Cmn	86	64*	98	73**	94*	92*	96*	94**	93	88	105	100
MEAN	94	96	99	101	100	94	104	100	102	100	107	105

[1] %HP = percent of high parent.

[2] %MP = percent of midparent.

Note: Significantly (*) or highly significantly (**) different than its high-parent or its midparent based on LSD.

essentially the same and approached their midparent means. No hybrid headed significantly earlier than its early parent in either generation. However, a significant midparent deviation for earliness was observed in three F_2 hybrids (Table IV). Eight F_2 hybrids headed significantly later than their respective earlier parents and one F_2 (Sut/7654) was also significantly later than its midparent. Six of these eight F_2 hybrids also headed significantly later than their respective earlier parents as F_3. Eight of 15 F_3 hybrids headed significantly later than their respective earlier parents and one F_3 hybrid (Tmp 64/Sdy) was also significantly later than its midparent.

Plant Height. Data on plant height was recorded for the 1970 test only. Generally, the hybrids were as tall as the taller parent for both generations (Table IV). The mean value of both F_2 and F_3 hybrids for plant height ranged from values 16 cm taller than the shortest parent, Sdy, to values 1 cm taller than the tallest parent, Ag. However, most of the hybrids were within 10 cm of their midparent values. None of the hybrids in either generation was significantly taller than its taller parent. Significant positive midparent deviations for plant height were observed in seven F_2 hybrids. Five of these seven hybrids were also significantly taller than their respective midparents in the F_3 generation.

Spike Number. Spike number was recorded in 1970 as well as 1971. The test in 1971 showed a definite reduction in number of spikes. The mean number of spikes for all entries per plot was 61 in 1970 as compared to 43 in 1971. This points out the importance of environmental conditions in regard to degree of expression in this trait. Also, several hybrids had positive parental deviations in 1970 but exhibited negative parental deviations in 1971. Most hybrids were somewhat lower in number of spikes than their high parents but were similar to the midparent in both years.

In 1970, nine F_2 hybrids were higher than their respective midparents and four F_2 hybrids were higher than their respective high parents. However, only two F_2 hybrids, Tmp 64/7654 and Sdy/Cmn, were significantly greater than their midparent values for this trait. Most of the hybrids that exceeded their midparent in yield also exceeded their midparent for number of spikes. One F_2 hybrid, Sut/7654, was significantly lower than its respective midparent and one F_3 hybrid, Ag/Cmn, was significantly lower than its midparent. None of the F_3 hybrids showed significant positive high-parent deviation for number of spikes and only one F_3 hybrid, Tmp 64/Sdy, exceeded its midparent by a significant margin.

In 1971, four of 15 F_2 hybrids exceeded their respective high parents for number of spikes and six of 15 F_2's exceeded their respective midparents. However, in no case was there a significant positive or negative deviation for the F_2's in 1971.

Nine of 15 F_3's exceeded their respective midparents and five of 15 F_3's exceeded their respective high parents for number of spikes in 1971. However, only one F_3 hybrid, Ag/7654, significantly exceeded its midparent for this trait. Only one F_3 hybrid, Sdy/Cmn, was significantly lower than its high-parent or midparent for this trait (Table V). The Tmp 64/7654 F_2 hybrid had the greatest number of spikes of all entries in the 1970 test, while the Ag/7654 F_3 hybrid was the highest entry for this trait in 1971. Both these hybrids also exhibited the largest positive high-parent deviation for this trait.

Kernel Weight. In 1970, the mean kernel weight of both F_2 and F_3 hybrids was slightly higher than the midparent but slightly lower than the high-parent mean value (Table IV). All but two of the 15 F_2's were higher than their respective midparents and five F_2's were higher than their respective high parents. However, only one hybrid, Tmp 64/Sdy, exceeded its midparent by a significant margin for this trait (Table IV). This hybrid was also the highest yielding entry in the test. Most of the F_2 hybrids that exceeded their midparents in yield also exceeded their midparents for this trait.

Nine of the 15 F_3's were higher than their respective midparents but only one, 7654/Sdy was significantly higher. Four of the 15 F_3's were higher than their respective high parents but none were significantly higher. However, two F_3 hybrids were significantly lower than their respective high parents for kernel weight (Table IV).

In 1971, the mean kernel weight of all the F_2 hybrids equalled the high-parent mean value while the mean of all the F_3 hybrids was similar to the midparent value (Table V). Five of the 15 F_2's exceeded their respective high parents, however, only one hybrid, 7654/Sdy, was significantly better. Significant positive midparent deviations for kernel weight occurred in ten of the 15 F_2's, three of which significantly exceeded their respective midparents in yield. Only one F_2 hybrid was significantly lower in kernel weight than its midparent.

All F_3's except one, Tmp 64/Cmn, were lower than their respective high parents for this trait. However, in only eight of the hybrids was this difference significant. Three of these eight hybrids were also significantly lower than their respective midparents. Significant positive midparent deviations for kernel weight was observed in three F_3 hybrids, Sut/Ag, Tmp 64/Ag, and Tmp 64/Cmn. These three F_3 hybrids were also significantly better than their respective midparent values for this trait in the F_2's (Table V). The Tmp 64/Cmn F_2 hybrid had the heaviest kernel weight in 1971 (Appendix Tables XXX and XXXIII). The lowest kernel weight occurred consistently in the 7654/Cmn F_3 hybrid over the two test years.

Grain Yield. As a group, the hybrids in 1970 were approximately 5% lower than the high-parent mean value but were similar to the midparent mean. The mean yield of all hybrids in 1971 was approximately 6% higher than the midparent mean value but similar to the high-parent mean. For the two year average the 15 hybrids in the F_2 and F_3 generation exceeded the midparent values by 5% and 2%, respectively (Tables IV and V).

In 1970, none of the F_2 hybrids yielded significantly higher than its high-parent. Nine F_2 hybrids were higher than their respective midparents in grain yield in 1970 but in only one case (Tmp 64/Sdy) was this difference statistically significant. This hybrid was also the highest yielding entry in the test. It yielded 7% better than its high-parent and 15% better than its midparent value (Table IV). No F_2 hybrid was significantly lower than its high-parent or midparent for this trait.

None of the F_3 hybrids exhibited significant positive midparent deviation for yield. No F_3 hybrid was significantly lower than its midparent value and only one, Sut/Sdy, was significantly lower in yield than its high-parent value (Table IV).

In 1971, nine F_2 hybrids were higher than their respective high parents, although only one hybrid, Ag/7654, was significantly so (Table V). This hybrid was also the highest yielding entry in the test. All but one of 15 F_2's exceeded their respective midparents, however, in only four of the hybrids, Sut/Tmp 64, Sut/7654, Sut/Sdy, and Ag/7654, was this difference significant. Three of these four hybrids also exhibited significant positive midparent deviations for kernel weight. No F_2 hybrid was significantly lower in yield than its high-parent or midparent.

Six of 15 F_3 hybrids were higher than their respective high parents in grain yield in 1971, although only one hybrid, Sut/Cmn, was significantly so. Most of the F_2 hybrids that exceeded their midparents for yield also exceeded their midparents for this trait as F_3's.

All but two F_3 hybrids exceeded their respective midparents in 1971, although in only four hybrids, Sut/Tmp 64, Sut/Ag, Sut/7654, and Sut/Cmn, was this difference significant. Three of these four hybrids were higher in grain yield than their corresponding F_2 counterparts. No F_3 hybrid was significantly lower in grain yield than its high-parent or midparent (Table V).

As an average of two years the highest yielding entry was the Ag/7654 F_2 hybrid which was followed closely by the Sut/Ag F_2 hybrid. The Ag/7654 F_2 hybrid yielded 408 grams/plot which was 12% better than its high-parent and 17% better than its midparent value. This hybrid also exhibited the highest positive high-parent deviation for yield as an average over two years. The Sut/Ag F_2 hybrid averaged 406 grams/plot which was 4% better than its high-parent and 8% better than its midparent value. Ag/Sdy F_2 and Ag/Sdy F_3 hybrids were the lowest yielding entries averaged over two years.

Diallel Analysis for General and Specific Combining Ability

All diallel crosses (F_1 through F_3) were subjected to a diallel analysis for general and specific combining ability for each character evaluated. The F_1 and F_2 generations grown in 1969 comprised a seven-parent diallel system, while the F_2 and F_3 generations, grown both in 1970 and 1971, formed a six-parent diallel cross.

Seven-Parent Diallel Test of F_1's and F_2's -- 1969

The mean squares from the analysis of variance of six characters on 21 F_1's and 21 F_2's are presented in Appendix Tables XXV and XXXVI. There were highly significant differences among hybrids for the six characters in both generations. Combining ability mean squares and the relative magnitude of general to specific combining ability for the six characters are shown in Table VI. Highly significant general and specific combining ability variances were observed for all characters in both generations.

The relative magnitude of the general combining ability variance for all traits across both generations was much larger than the specific combining ability variance except for grain yield in the F_2 generation. Ratios of general to specific combining ability of the F_1's and F_2's were of similar magnitude for heading date, plant height, spike number and kernel weight. The relative magntidue of general to specific combining ability variance for kernels/spike was quite large in the F_1's (21:1) in comparison with the F_2's (3:1). The genetic variability for heading date and plant height was largely accounted for by general combining ability. The ratios of general to specific combining ability variance for these

TABLE VI

OBSERVED MEAN SQUARES FOR GENERAL COMBINING ABILITY, SPECIFIC COMBINING ABILITY AND ERROR FOR SIX CHARACTERS AND THE RATIO OF GENERAL TO SPECIFIC COMBINING ABILITY FROM SEVEN-PARENT DIALLEL CROSS, 1969

Character	Generation	G.C.A.[1]	S.C.A.[2]	Error	G.C.A./S.C.A.
Heading Date	F_1	12.767**	0.897**	0.02	14:1
	F_2	12.387**	1.563**	0.09	8:1
Plant Height	F_1	178.867**	9.604**	4.411	19:1
	F_2	84.281**	7.904**	0.809	11:1
Spike Number	F_1	11.054**	3.499**	0.287	3:1
	F_2	2.987**	0.953**	0.306	3:1
Kernel Weight	F_1	0.519**	0.132**	0.003	4:1
	F_2	0.275**	0.157**	0.005	2:1
Kernels/Spike	F_1	21.919**	1.022**	0.176	21:1
	F_2	11.804**	4.274**	0.268	3:1
Grain Yield	F_1	21.951**	7.179**	0.382	3:1
	F_2	1.167**	2.450**	0.406	1:2

[1] G.C.A. = general combining ability.

[2] S.C.A. = specific combining ability.

*Significance at 5% level.

**Significance at 1% level.

Note: The degrees of freedom associated with G.C.A., S.C.A., and error are 6, 14, 504, respectively.

traits were high for both generations (Table VI). The ratio of general to specific combining ability variance for number of spike was 3:1 for both generations. The ratio of general to specific combining ability variance for kernel weight was on the order of 3:1. The ratio of general to specific combining ability variance for grain yield was 3:1 in the F_1 generation while a ratio of 1:2 was obtained in the F_2 generation. This suggests that non-additive genetic effects were slightly more important than additive effects in the F_2.

Estimates of General Combining Ability Effects. Since general combining ability variances were significant for all cases in the seven-parent diallel cross, general combining ability effects of parents were estimated for all characters measured. The general combining ability effects of individual parental lines along with the corresponding standard errors for each character are presented in Table VII. For heading date, Tmp 64 and Sdy had the greatest negative general combining ability effects (earliness) in both generations. The Tmp 64, Sdy and Danne parents consistently had the greatest significant negative general combining ability effects for plant height in both generations. High negative effects, indicating shortness of straw, are desirable in this case.

Ag had consistently high general effects for yield across both generations while Sut had consistently low general effect for this trait. The parents, Cmn and 7654 showed consistently high general effects for spike number while Sdy and Danne showed consistently low general effects for this trait across both generations. Tmp 64 and Sdy had significantly higher positive general effects for kernel weight than the other five parental lines across both generations. Ag, Cmn, and 7654 were found to be consistently low in general effects for this trait. Ag consistently

TABLE VII

ESTIMATES OF GENERAL COMBINING ABILITY EFFECTS FOR SIX CHARACTERS FROM A SEVEN-PARENT DIALLEL CROSS GROWN AS F_1 AND F_2 HYBRIDS IN 1969

Character	Generation	Sut	Tmp 64	Ag	7654	Sdy	Cmn	Danne	S.E. $(\hat{g}_i - \hat{g}_j)$
Heading Date	F_1	0.95	-1.87	2.00	0.68	-1.85	1.27	-1.16	0.09
	F_2	0.81	-1.75	2.21	-0.11	-1.75	1.54	-0.97	0.19
Plant Height	F_1	0.93	-3.57	7.00	4.25	-9.91	4.84	-3.57	1.33
	F_2	1.39	-3.24	2.81	2.62	-6.71	5.02	-1.88	0.57
Spike Number	F_1	0.06	0.38	1.08	0.75	-2.28	1.78	-1.75	0.34
	F_2	0.51	-0.10	-0.21	0.82	-1.38	0.72	-0.36	0.35
Kernel Weight	F_1	-0.03	0.58	0.02	-0.31	0.23	-0.13	-0.34	0.03
	F_2	0.06	0.30	-0.30	0.01	0.18	-0.33	0.08	0.04
Kernels/Spike	F_1	-2.96	-2.23	2.78	0.00	1.10	-0.54	1.83	0.27
	F_2	-1.72	-1.59	2.22	-1.28	0.38	1.06	0.91	0.33
Grain Yield	F_1	-2.87	0.50	3.83	-0.62	-0.23	0.81	-1.43	0.39
	F_2	-0.67	-0.13	0.37	-0.27	-0.20	0.08	0.82	0.40

had, by far, the greatest positive general effects for kernels/spike while Sut had the largest negative effects for this trait. Considering general combining ability effects for yield, kernels/spike and spike number, Ag appeared to be the best parent in this set.

Estimates of Specific Combining Ability Effects. Since specific combining ability variances were significant in all cases in the seven-parent diallel cross, estimates of specific combining ability effects associated with individual crosses were computed. These are presented in Table VIII. Shown also in this table are standard errors for comparison of effects of two crosses having one parent in common.

Eight crosses showed significantly negative (earliness) specific combining ability effects for heading date in both generations. Three of them involved the semi-dwarf parent, Sdy and three involved Tmp 64. Specific combining ability effects for plant height were quite variable between generations. The Sdy/Cmn hybrid had the greatest significant negative (shortness) effect in the F_1 but was not significantly different from the population mean in the F_2.

Eight of the 21 F_1's exhibited significant positive specific combining ability effects for yield while only four showed significant positive effects as F_2. Three hybrids, Ag/7654, Tmp 64/7654, and Cmn/Danne consistently showed significant positive specific effects for yield across both generations. The greatest positive specific effect for yield occurred in the Ag/7654 hybrid across both generations. This hybrid also had positive effects for the three yield components, and was especially high for spike number (Table VIII). This indicates that this particular cross would be potentially variable in a breeding program where grain yield is of prime consideration. Four hybrids showed significant

TABLE VIII

ESTIMATES OF SPECIFIC COMBINING ABILITY EFFECTS FOR SIX CHARACTERS FROM A SEVEN-PARENT DIALLEL CROSS GROWN AS F_1 AND F_2 HYBRIDS IN 1969

Hybrid	Heading Date		Plant Height		Spike Number		Kernel Weight		Kernels/Spike		Grain Yield	
	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
Sut/Tmp 64	-0.87	-1.13	0.20	2.84	0.49	0.83	0.27	-0.11	-0.30	1.98	0.73	2.06
Sut/Ag	0.37	0.69	3.07	-0.32	0.28	-0.53	0.31	0.45	1.23	-1.60	3.15	0.14
Sut/7654	0.69	0.78	-1.37	-1.33	1.39	-0.43	-0.36	-0.40	-1.94	0.23	-2.06	-1.76
Sut/Sdy	-0.46	-0.64	0.24	-4.03	0.89	-0.95	0.00	0.15	0.72	-0.51	1.63	-0.85
Sut/Cmn	0.39	1.30	1.09	3.54	1.15	0.54	0.05	-0.49	-0.44	2.45	0.15	0.62
Sut/Danne	-0.12	-1.01	-3.24	-0.70	-4.20	0.53	-0.17	0.39	0.73	-2.54	-3.60	-0.21
Tmp 64/Ag	-0.58	-0.91	-1.48	0.17	-1.19	-0.54	0.16	0.44	-1.50	-2.94	1.84	-0.94
Tmp 64/7654	-0.85	-1.06	-1.60	0.77	0.89	0.74	0.10	-0.11	0.18	1.20	1.52	0.89
Tmp 64/Sdy	1.56	1.36	1.84	-2.32	-0.93	-1.13	-0.53	-0.31	1.11	1.89	-1.95	-0.86
Tmp 64/Cmn	-0.37	-0.17	-3.05	1.18	-0.04	-0.44	0.04	0.36	0.47	-2.62	0.72	-0.91
Tmp 64/Danne	1.12	1.90	4.10	-2.63	0.77	0.54	-0.04	-0.28	0.04	0.49	0.82	-0.24
Ag/7654	0.79	0.58	0.61	1.94	2.06	1.26	0.21	0.10	0.43	1.01	3.83	2.54
Ag/Sdy	-1.30	-1.35	-0.15	-0.45	-0.51	0.05	-0.05	-0.02	-0.89	0.51	-1.83	0.39
Ag/Cmn	0.71	1.15	-0.68	-0.03	-0.09	0.67	0.10	-0.52	0.15	1.79	0.56	-0.37
Ag/Danne	0.01	-0.16	-1.34	-1.30	-0.56	-0.91	-0.73	-0.46	0.58	1.24	-3.86	-1.76
7654/Sdy	-0.38	1.22	-1.64	3.56	-1.61	1.05	0.30	-0.18	0.39	0.42	-0.03	0.57
7654/Cmn	0.59	-0.47	6.49	-5.02	-2.32	-1.33	-0.38	0.21	0.41	-2.48	-3.58	-2.53
7654/Danne	-0.85	-1.06	-2.48	0.09	-0.42	-1.28	0.12	0.38	0.53	-0.38	0.31	0.30
Sdy/Cmn	-0.28	-1.36	-3.57	-0.49	-0.48	0.21	-0.13	0.42	-0.01	-1.32	-0.99	1.02
Sdy/Danne	0.87	0.77	3.28	3.73	2.64	0.76	0.41	-0.06	-1.32	-0.99	3.18	-0.27
Cmn/Danne	-1.03	-0.45	-0.28	0.81	1.78	0.35	0.41	0.02	-0.57	2.17	3.14	2.18
S.E. ($\hat{S}ij-\hat{S}ik$)	0.18	0.38	2.66	1.14	0.68	0.70	0.07	0.09	0.53	0.65	0.78	0.81

negative specific effects for grain yield across both generations. The largest negative effect was found in three hybrids, Ag/Danne, Sut/7654, and 7654/Cmn, two of which exhibited necrotic symptoms. The 7654/Cmn hybrid had the greatest negative effects for number of spikes as an average of both generations, while the Ag/Danne hybrid and Sut/7654 hybrid had significant negative effects for kernel weight across both generations.

Six-Parent Diallel Test of F_2's and F_3's -- 1970 and 1971

These generations were evaluated both in 1970 and 1971 in Stillwater. The analysis was made on each year separately and also on combined years. The combined analysis was conducted for three traits, spike number, kernel weight, and grain yield, and permitted an examination of the combining ability x environmental (year) interaction.

In 1970, there were highly significant differences among hybrids for heading date, plant height, and number of spikes for both generations. Highly significant differences among hybrids were observed for kernel weight and yield in the F_3 generation but these characters were not significant in the F_2 generation (Appendix Tables XXXVII and XXXVIII). Combining ability mean square and the relative magnitude of general to specific combining ability for the five characters from the 1970 test are presented in Table IX. General combining ability variances for all five traits were significant or highly significant in both generations. Specific combining ability variances for number of spikes and yield were highly significant and significant specific combining ability variance was observed for plant height in the F_2 generation but not for the F_3 generation. Significant or highly significant specific combining ability

TABLE IX

OBSERVED MEAN SQUARES FOR GENERAL COMBINING ABILITY, SPECIFIC COMBINING ABILITY AND ERROR FOR FIVE CHARACTERS AND THE RATIO OF GENERAL TO SPECIFIC COMBINING ABILITY FROM SIX-PARENT DIALLEL CROSS, 1970

Character	Generation	G.C.A.[1]	S.C.A.[2]	Error	G.C.A./S.C.A.
Heading Date	F_2	8.243**	0.315	0.208	26:1
	F_3	7.355**	0.468*	0.220	16:1
Plant Height	F_2	6.725**	1.578*	0.788	4:1
	F_3	4.538**	0.898	0.695	5:1
Spike Number	F_2	15.837*	18.223**	5.499	1:1
	F_3	31.358**	11.782	8.452	3:1
Kernel Weight	F_2	0.166**	0.013	0.023	13:1
	F_3	0.068**	0.04 *	0.018	2:1
Grain Yield	F_2	7.566*	9.315**	3.582	1:1
	F_3	9.926**	1.720	2.919	6:1

[1] G.C.A. = general combining ability.

[2] S.C.A. = specific combining ability.

*Significance at 5% level.

**Significance at 1% level.

Note: The degree of freedom associated with G.C.A., S.C.A., and error are 5, 9, and 70, respectively.

variances were observed for heading date and kernel weight for the F_3 generation and for plant height, spike number and grain yield for the F_2 generation. Ratios of general to specific combining ability of the F_2's were of similar magnitude to the F_3's for heading date, plant height and spike number but not for kernel weight and grain yield. The highest average general to specific combining ability variance ratio (21:1) was obtained for heading date. For plant height the ratio was on the order of 5:1. The lowest average general to specific combining ability ratio (2:1) was obtained for number of spikes. The ratio of general to specific combining ability variance for kernel weight was quite large in the F_2 (13:1) but relatively small in the F_3 (2:1). In 1970 the ratio of general to specific combining ability variance for grain yield was 1:1 for the F_2's but was much higher (6:1) for the F_3's. This suggests that non-additive genetic effects were as important as additive effects for this trait in the F_2 generation or perhaps indicates the problems of obtaining accurate combining ability estimates for complex characters such as grain yield.

In 1971, mean squares among hybrids were highly significant for kernel weight and grain yield in both generations. Highly significant and significant differences among crosses were observed for spike number for the F_2's and F_3's, respectively (Appendix Tables XXXVII and XXXVIII). General combining ability mean squares and the relative magnitude of general to specific combining ability variances for the three characters are presented in Table X. General combining ability variances for all characters were highly significant in both generations. Specific combining ability variances for kernel weight were highly significant both in the F_2 and F_3 generations. Specific combining ability variances for

TABLE X

OBSERVED MEAN SQUARES FOR GENERAL COMBINING ABILITY, SPECIFIC COMBINING ABILITY AND ERROR FOR THREE CHARACTERS AND THE RATIO OF GENERAL TO SPECIFIC COMBINING ABILITY FROM SIX-PARENT DIALLEL CROSS, 1971

Character	Generation	G.C.A.[1]	S.C.A.[2]	Error	G.C.A./S.C.A.
Spike Number	F_2	24.456**	13.271	8.336	2:1
	F_3	51.406**	19.730**	7.151	3:1
Kernel Weight	F_2	0.211**	0.031**	0.009	7:1
	F_3	1.157**	0.369**	0.007	3:1
Grain Yield	F_2	19.026**	3.714*	1.765	5:1
	F_3	30.736**	1.110	1.849	28:1

[1] G.C.A. = general combining ability.

[2] S.C.A. = specific combining ability.

*Significance at 5% level.

**Significance at 1% level.

Note: The degree of freedom associated with G.C.A., S.C.A., and error are 5, 9, and 70, respectively.

spike number were highly significant for the F_3's but not for the F_2's. Significant specific combining ability variances were observed for yield for the F_2's but not for the F_3's.

Ratios of general to specific combining ability variances of the F_2's and F_3's were of similar magnitude for spike number and kernel weight and were in fair agreement with the ratios observed for these traits in the 1970 tests (Table IX). The ratio of general to specific combining ability variance for grain yield was relatively small (5:1) in the F_2's but quite large in the F_3's (28:1). This again suggests there were problems in obtaining reliable combining ability estimates for yield in these tests.

The diallel analysis for general and specific combining ability on combined years was conducted for the three characters: spike number, kernel weight and grain yield. Differences among hybrids were either significant or highly significant for all characters in both generations.

The combined analyses of variance shown in Table XI revealed significant years by hybrid's interactions for all traits. General and specific combining ability variances for the F_2's and F_3's were significant or highly significant for all characters studied except for specific combining ability for yield in the F_3 generation. Based on combined analyses the ratio of general to specific combining ability variances for spike number was nearly 1:1 for the F_2's but 4:1 for the F_3's. For kernel weight, the ratio was 3:1 and 7:1 for the F_2's and F_3's, respectively. The ratio of general to specific combining ability variances was nearly 1:1 for the F_2's but 13:1 for the F_3's for yield.

General combining ability by year interactions were significant for all characters in both generations. However, specific combining ability

TABLE XI

COMBINING ABILITY ANALYSES OF VARIANCE OF F_2 AND F_3 HYBRIDS FROM A SIX-PARENT DIALLEL CROSS IN 1970 AND 1971

Source of Variation	d.f.	Spike Number		Kernel Weight		Grain Yield	
		F_2	F_3	F_2	F_3	F_2	F_3
Years	1	3088.982	2273.602	4.800	3.115	67.599	21.675
Reps in Years	5	20.031**	18.017*	0.031*	0.039*	6.589**	4.993*
Hybrids	14	16.258*	34.216**	0.126**	0.107**	10.315**	10.703**
G.C.A.[1]	5	15.893*	65.077**	0.332**	0.234**	12.797**	26.149**
S.C.A.[2]	9	16.424*	17.071*	0.116**	0.036**	8.936**	2.122
Years x Hybrids	14	18.402**	15.602*	0.037*	0.055**	7.558**	5.637**
G.C.A. x Years	5	24.400**	17.689*	0.045*	0.066**	13.795**	14.513**
S.C.A. x Years	9	15.069*	14.442	0.033*	0.048**	4.092	0.705
Error	70	6.918	7.802	0.0164	0.013	2.673	2.384

[1] G.C.A. = general combining ability.

[2] S.C.A. = specific combining ability.

*Significant at 5% level.

**Significant at 1% level.

by year interactions were significant for only two traits. These were kernel weight across both generations, and spike number for the F_2. In general, the magnitude of general combining ability by year interaction components were larger than specific combining ability by year interaction components for both spike number and grain yield. For kernel weight, however, variances for general combining ability by year interaction and those for specific combining ability by year interaction were about equal across both generations.

Estimates of General Combining Ability Effects -- 1970 and 1971. Since general combining ability variances for the six-parent diallel cross were significant for all cases (Tables IX and X), general combining ability effects of parents were estimated for all characters. Estimates of general combining ability effects of individual parental lines along with the corresponding standard errors for each character in each year are presented in Table XII. For heading date, Tmp 64 and Sdy had the greatest negative general combining ability effects (earliness). Also, Tmp 64 and Sdy consistently had the greatest significant negative general combining ability effects for plant height. High negative effects are desirable in this case since it indicates shortness of straw. The Sut parent, had by far the greatest positive general combining ability effects for yield in all comparisons while Sdy showed consistently low general effects for this trait. General combining ability effects for spike number were quite variable from year to year. Sut and Tmp 64 showed consistently high general effects across both generations in 1970 but not in 1971. Sdy was consistently low for this trait in all comparisons. Sut and Tmp 64 had significantly higher positive general combining ability effects for kernel weight than the other four parental lines. Ag

TABLE XII

ESTIMATES OF GENERAL COMBINING ABILITY EFFECTS FOR FIVE CHARACTERS FROM A SIX-PARENT DIALLEL CROSS GROWN AS F_2 AND F_3 HYBRIDS IN 1970 AND 1971

Character	Generation	Year	Sut	Tmp 64	Ag	7654	Sdy	Cmn	S.E. $(\hat{g}_i-\hat{g}_j)$
Heading Date	F_2	70	0.07	-2.06	1.28	0.65	-1.39	1.44	0.32
		71	--	--	--	--	--	--	--
	F_3	70	-0.60	-1.97	1.44	0.03	-0.52	1.61	0.33
		71	--	--	--	--	--	--	--
Plant Height	F_2	70	1.21	-1.25	0.75	-0.67	-1.50	1.46	0.63
		71	--	--	--	--	--	--	--
	F_3	70	-0.05	-1.35	1.36	-0.01	-0.97	1.03	0.59
		71	--	--	--	--	--	--	--
Spike Number	F_2	70	2.89	1.33	-1.40	0.87	-2.00	-1.71	1.66
		71	-0.46	-1.52	2.23	-0.09	-3.46	3.33	2.04
	F_3	70	2.89	3.02	-1.86	1.10	-1.17	-3.96	2.06
		71	3.49	-1.37	0.29	4.88	-3.57	-3.68	1.89
Kernel Weight	F_2	70	0.15	0.29	-0.08	-0.23	-0.19	0.04	0.11
		71	0.37	0.20	-0.17	-0.08	-0.19	-0.12	0.07
	F_3	70	0.12	0.18	-0.04	0.02	-0.11	-0.17	0.09
		71	0.31	0.28	-0.11	-0.29	-0.10	-0.06	0.06
Grain Yield	F_2	70	2.01	1.10	-1.16	-0.66	0.28	-1.54	1.34
		71	2.12	-0.94	0.98	1.27	-3.94	0.51	0.94
	F_3	70	1.46	2.15	-1.96	0.19	-1.14	-0.70	1.21
		71	4.39	-1.41	-0.04	-0.04	-4.00	1.07	0.96

and Sdy were consistently low in general effects for this trait. When general combining ability effects for all traits are considered across all comparisons Sut appeared to be the best parent in this set.

Estimates of Specific Combining Ability Effects -- 1970 and 1971.

With respect to the six-parent diallel cross, estimates of specific bining ability variances were quite variable for most characters between different generations tested in the same year or the same generation tested in different years. Since specific combining ability variances were statistically significant for grain yield across both years in the F_2 generation and for kernel weight in the F_3 generation, estimates of specific combining ability effects were computed for these two cases only (Table XIII). In 1970, only one cross, Tmp 64/Ag had significant positive effects for kernel weight, while three crosses had significant negative effects for this trait. In 1971, two crosses, Tmp 64/Cmn and 7654/Sdy had significant positive effects for kernel weight, while one cross had significant negative effects for this trait.

Three of the 15 F_2's exhibited significant positive specific combining ability effects for grain yield in 1970. In 1971, only one hybrid showed significant positive effect for this trait. The greatest positive effect for yield in 1970 occurred in the Tmp 64/Sdy hybrid followed by the Sut/Ag and Ag/7654 hybrid. However, Tmp 64/Sdy and Sut/Ag showed lower and nonsignificant specific effects for this trait in 1971. The Ag/7654 hybrid had a high positive significant effect for grain yield in 1971 (Table XIII). Considering specific combining ability effects of all 15 F_2 hybrids in both years the Ag/7654 hybrid had the greatest positive effect for grain yield. The largest negative effect for grain yield was exhibited by the Ag/Sdy hybrid. Other hybrids with consistently large

TABLE XIII

ESTIMATES OF SPECIFIC COMBINING ABILITY EFFECTS FOR KERNEL WEIGHT AND FOR GRAIN YIELD FROM A SIX-PARENT DIALLEL CROSS

Hybrid	Kernel Weight		Grain Yield	
	F_3		F_2	
	1970	1971	1970	1971
Sut/Tmp 64	0.06	-0.10	-2.81	0.83
Sut/Ag	-0.32	0.06	3.60	-0.57
Sut/7654	0.09	0.16	-1.78	-0.92
Sut/Sdy	-0.01	-0.00	0.01	1.30
Sut/Cmn	0.18	-0.11	0.98	-0.63
Tmp 64/Ag	0.24	-0.00	-0.77	-1.25
Tmp 64/7654	0.03	-0.26	0.23	-1.27
Tmp 64/Sdy	-0.27	0.00	4.09	0.36
Tmp 64/Cmn	-0.06	0.36	-0.78	1.33
Ag/7654	0.08	0.00	2.83	4.23
Ag/Sdy	0.06	-0.11	-5.42	-1.71
Ag/Cmn	-0.07	0.05	-0.24	-0.70
7654/Sdy	0.03	0.26	-0.02	-0.99
7654/Cmn	-0.24	-0.15	-1.29	-1.05
Sdy/Cmn	0.19	-0.15	1.33	1.04
S.E. ($\hat{S}ij-\hat{S}ik$)	0.19	0.16	2.30	2.09

negative effects for grain yield across both years were Sut/7654 and 7654/Cmn.

Based on all tests, no parent consistently had positive general combining ability effects for grain yield. Ag had high general effects in the seven-parent diallel test while Sut showed high effects in the six-parent diallel test. However, Sdy consistently had negative general effects for grain yield across all tests. The Ag/7654 hybrid consistently had positive specific combining ability effects for grain yield across all tests while the Sut/7654 and 7654/Cmn hybrids consistently had negative effects for this trait.

Predictive Values

Inter-generation correlations are used as a measure of the relationship between midparent, F_1 and F_2 and between F_2 and F_3 generations for each character for predictive purposes.

Seven-Parent Diallel Test of F_1's and F_2's -- 1969

Correlation coefficients for six characters were determined between midparent values, F_1, and F_2 hybrids grown in 1969 (Table XIV). The performance of the F_1's was highly associated with the F_2 performance for heading date and plant height. The associations between the midparent value and the F_1 and between the midparent and the F_2 for these two traits were low and not statistically significant. The correlations for spike number involving the midparent, F_1, and F_2 were significant but not strikingly large (r value of 0.5). The F_1 performance was not significantly correlated with either the midparent value or the F_2 performance for kernel weight. However, the association for kernel weight between

TABLE XIV

SIMPLE CORRELATION COEFFICIENTS BETWEEN GENERATIONS OF SEVEN-PARENT DIALLEL CROSS GROWN AS F_1 AND F_2 HYBRIDS IN 1969[1]

Generations Correlated	Heading Date	Plant Height	Spike Number	Kernel Weight	Kernels/Spike	Grain Yield
M-P[2] vs F_1	0.369	-0.191	0.598**	0.205	0.848**	0.108
M-P vs F_2	0.219	0.150	0.530*	0.510*	0.396	0.159
F_1 vs F_2	0.928**	0.776**	0.578**	0.401	0.411	0.430*

[1] At 19 d.f.; r .05 = 4.33; r .01 = .549.

[2] M-P = midparent.

*Significant at 5% level.

**Significant at 1% level.

the midparent value and the F_2 performance was statistically significant. Correlations for kernels/spike were significant only for the comparison made between the midparent value and the F_1 generation. Correlations for grain yield between the midparent value and the F_1 generation and between the midparent and the F_2 generation were quite low. However, a relatively low but significant association ($r = 0.4$) was observed between the F_1 and F_2 generations for grain yield.

Six-Parent Diallel Test of F_2's and F_3's -- 1970 and 1971

Correlation coefficients were computed for all characters measured between generations of the crosses resulting from the six-parent diallel system evaluated in 1970 and 1971. In the 1970 test, correlations involving the midparent, F_2's and F_3's both for heading date and plant height were statistically significant in all cases (Table XV). Correlations for number of spikes were not significant. The correlation for kernel weight in 1970 was significant only for the comparison made between the midparent value and the F_2 generation. The correlations for grain yield between the midparent value and the F_3 performance and between the F_2 performance and the F_3 in 1970 were significant but not strikingly large.

A significant but not strikingly large correlation coefficient was observed between the midparent value and the F_2 generation for spike number in the 1971 test (Table XVI). Correlations for kernel weight were highly significant in all comparisons from 1971. All correlations for grain yield involving the midparent, F_2's and F_3's grown in 1971 were prominent and highly significant.

Based on both tests, the midparent value was not correlated with the

TABLE XV

SIMPLE CORRELATION COEFFICIENTS BETWEEN GENERATIONS OF SIX-PARENT DIALLEL CROSS GROWN AS F_2 AND F_3 HYBRIDS IN 1970[1]

Generations Correlated	Heading Date	Plant Height	Spike Number	Kernel Weight	Grain Yield
M-P[2] vs F_2	0.845**	0.582*	0.446	0.878**	0.469
M-P vs F_3	0.942**	0.547*	0.395	0.476	0.583*
F_2 vs F_3	0.895**	0.635*	0.451	0.274	0.571*

[1] 13 d.f.; r .05 = .514; r .01 = .641.

[2] M-P = midparent.

*Significant at 5% level.

**Significant at 1% level.

TABLE XVI

SIMPLE CORRELATION COEFFICIENTS BETWEEN GENERATIONS OF SIX-PARENT DIALLEL CROSS GROWN AS F_2 AND F_3 HYBRIDS IN 1971[1]

Generations Correlated	Spike Number	Kernel Weight	Grain Yield
M-P[2] vs F_2	0.558*	0.743**	0.796**
M-P vs F_3	0.116	0.658**	0.800**
F_2 vs F_3	0.196	0.755**	0.731**

[1] 13 d.f.; r .05 = .514; r .01 = 641.

[2] M-P = midparent.

*Significant at 5% level.

**Significant at 1% level.

F_1 generation for grain yield. However, some degree of correlation was found between the midparent value and the F_2 generation and a good correlation was found between the midparent value and the F_3 generation for this trait. Some degree of correlation for yield was observed between the F_1 and F_2 generation and a good correlation was observed between the F_2 and F_3 generation.

CHAPTER V

DISCUSSION

A critical test of several agronomic characters for the expression of heterosis and inbreeding depression was one of the main objectives of this experiment. In evaluating expression of heterosis for grain yield, the comparison of the F_1 with its high-parent rather than with its midparent is a better measure of performance as far as commercial hybrid wheat production is concerned. Furthermore, the ultimate test as far as the commercial wehat grower is concerned is how the F_1 hybrids perform in relation to the best commercial varieties already available.

The results from the seven-parent diallel cross conducted in hill-planted plots showed six individual cases of high-parent heterosis for yield in the F_1 populations. All six of these hybrids exhibited significant midparent heterosis for kernel weight suggesting that at least part of the heterosis for yield must have been due to an increase in kernel weight. Three of these six F_1 hybrids, Ag/7654, Ag/Cmn, and Sut/Ag, produced yields that were 40, 33, and 28% above their respective high parents. These hybrids were respectively 32, 25, and 20% better than Tmp 64, the highest yielding pure-line variety in the test. If it is assumed that a level of heterosis of about 20% over the best commercial variety is necessary for economically feasible commercial hybrid wheat production, and if the information from this test is valid, then three of the 21 hybrids tested meet this requirement.

It is of interest to compare these results with that of a previous study of the same F_1 hybrids also tested in hill-planted plots. Lee and Smith (27) found the average level of high-parent heterosis to be less than that obtained in the present study (5% vs 11%). In the previous study, four hybrids showed significant midparent heterosis for yield. Of these four hybrids, three of them were among the six hybrids in the present study that showed significant high-parent heterosis indicating good agreement between the two studies.

The level of high-parent heterosis obtained in this study was similar to that of Bitzer and Fu (4) but still rather low compared to other wheat studies (21,17,30) where the average heterosis of a series of hybrids was about 25% above the high-parent. The heterosis analyses reported herein were conducted on a fixed model basis (11). The conclusions must, therefore, apply to the populations as constituted by the experimental material. Therefore, other hybrid combinations or tests conducted in other years or at other locations may result in different degrees of heterosis. In any even, the results from the present study together with those of the previous study with the same set of hybrids (27) indicate that certain F_1 combinations consistently showed sufficient levels of heterosis to warrant further investigations on the development of hybrid wheats for this region.

In the seven-parent diallel study, the mean yield of all F_2 hybrids tested under hill-planted conditions was equal to the high-parent average. The mean yield of all 15 F_2 hybrids tested under nursery plot conditions as the six-parent diallel cross over two years was also similar to the high-parent average. This indicates that even though yield heterosis of wheat crosses was reduced appreciably from F_1 to F_2, the F_2

hybrids as a group were as productive as their high parents. Use of F_2's, however, might be feasible with a chemical gametocide system but probably would not be with cytoplasmic male sterile and genetic restorer systems.

The degree of inbreeding depression for yield and yield components in the F_2 appeared to be in most cases related to the degree of heterosis that occurred in the F_1 hybrids. The F_1 hybrids which displayed the greater heterosis tended to show the greater inbreeding depression in the F_2 generation. In this study, three F_1 hybrids, Ag/7654, Ag/Cmn, and Sut/Ag, which exhibited the greatest high-parent heterosis also exhibited the greater inbreeding depression for yield as measured by the ratio: F_2/F_1. These three hybrids were also the three highest yielding hybrids in the test.

In this study, significant high-parent heterosis for yield was observed in six hybrids in which significant midparent heterosis for kernel weight was recorded. Three of these six hybrids exhibited significant inbreeding depression for yield. All of these three hybrids also exhibited significant inbreeding depression for kernel weight. These findings strongly suggest that kernel weight is the major yield component which contributes to either heterosis or inbreeding depression for yield.

The results of performance of hybrids from both tests revealed that a definite and progressive reduction in yield took place in the crosses as selfing led to a progressive increase in homozygosity. In the 1969 hill-planted experiment, the mean increase of the F_1 hybrids over the midparent means was 16% and dropped to 4% for the F_2 hybrids compared with the midparents. In 1970, the mean increase of the F_2's and F_3's over the midparent values was 3% and -2%, respectively, while the mean increases of 7% and 5% over the midparent values were recorded for the F_2's and F_3's, respectively in 1971. As an average of two years, however, the mean of the 15 hybrids in the F_2 and F_3 generations exceeded the midparent values by 5% and 3%, respectively. This indicated that the average yield of the F_3 hybrids approached, approximately, the mean yield of the parents. Assuming the expected percentage of homozygosity in the F_3 generation is only 75%, this reduction in yield appeared to be more than expected.

It was impossible to evaluate the role of genotype-environment interactions in the F_1 and F_2 generations of the seven-parent diallel study since these generations were tested in only one environment. However, the F_2 and F_3 generations of the 15 hybrids comprising the six-parent diallel system were evaluated for two successive years and a differential response of the hybrids in these two seasons was observed. In 1970, two F_2 hybrids, Sut/Tmp 64 and Sut/7654 yielded 9% and 11% less than their respective high parents, respectively. In 1971, however, the same hybrids yielded 7% and 8% more than their respective high parents, respectively. The opposite was true of two F_2 hybrids, 7654/Sdy and Sdy/Cmn, which outyielded their respective high parents by 8% and 10%, respectively in 1970. But in 1971 the same hybrids yielded 5% and 7% less than their respective high parents, respectively. Five of the 15 F_3 hybrids, Sut/Tmp 64, Sut/Ag, Sut/7654, Sut/Cmn, and Ag/Cmn exhibited positive high-parent deviation of 9%, 12%, 8%, 16%, and 2%, respectively in 1971. However, the same hybrids showed negative high-parent deviation of 7%, 13%, 12%, 10%, and 11%, respectively, in 1970. The lack of agreement between the performance of the same hybrids tested in different years indicated a hybrid by year interaction. Similar findings were reported by Gyawali, et al. (17) and Walton (48) in wheat. This suggests that the performance of early generation bulk hybrids must be tested over a number of seasons, or perhaps at a number of locations.

The results obtained from the combining ability study from the seven-parent diallel cross of F_1's and F_2's grown in 1969 indicated that both general combining ability and specific combining ability variance were important for heading date, plant height, spike number, kernel weight, and kernels/spike across both generations. However, variance component for general combining ability was much larger than that for specific combining ability in all cases, indicating that a large part of the total genetic variance for these five characters was due to additive gene action.

The combining ability estimates for grain yield were somewhat different. The ratio of general to specific combining ability variance for this trait was 3:1 in the F_1's and 1:2 in the F_2's. This suggests that non-additive genetic effects were of considerable importance for yield. In the study reported herein, heterosis was more prominent for grain yield than any other character, suggesting that non-additive genetic effects may be proportionately greater for grain yield than for any of the yield components. This would be consistent with the theory of the yield component approach to breeding.

Rojas and Sprague (37) found in maize that the specific combining ability variance component included not only the non-additive variation due to dominance and epistasis, but also a considerable portion of the genotype by environment interaction. Since the seven-parent diallel test was conducted at only one location in one year, estimates of combining ability may be biased by interactions with location and year effects. If important combining ability by location or year interaction effects were present, estimates of specific combining ability variance obtained only from one test would be biased upward and hence would be overestimated in this study.

On the basis of F_1 data alone, the pattern of general and specific combining ability variances for yield and yield components found in this study was similar to that reported by Lee and Smith (27) and was in good agreement with the results presented by Gyawali, et al. (17). The results obtained in this study for general combining ability were generally consistent with those of other workers. Less agreement was noted for the results on specific combining ability for yield and yield components. Brown, et al. (9) and Bitzer and Fu (4) did not detect significant variances due to specific combining ability in wheat while Kronstad and Foote (26) found significant variance for specific combining ability for yield only. Walton (48) did not detect significant variance due to specific combining ability in an eight-parent diallel cross but found significant variances for specific combining ability for yield and yield components in a five-parent diallel cross.

The diallel analysis for general and specific combining ability for the F_2's and F_3's of the six-parent diallel system was made on each year separately as well as on combined years which provided for an estimate of combining ability by year interactions. Estimates of general combining ability variances were high and significant for all traits for both generations for each year while specific combining ability variances were low and in many cases, not significant. From the combined analysis, the ratio of general to specific combining ability variance for grain yield for the F_3 generation was quite large (13:1), suggesting that the genetic system for this trait was mostly additive by the F_3 generation. This was consistent with the report by Grafius, et al. (15) that non-additive effects caused by dominance and epistasis will disappear rapidly under selfing. The predominance of additive genetic variance and the general absence of heterosis in the F_3 population suggested that selection leading to the isolation of homozygous lines appeared to be warranted in this generation.

Genotype by environment interactions may be of considerable importance in estimates of combining ability since significant year by general combining ability interactions were observed for spike number, kernel weight and grain yield in the six-parent diallel system tested in 1970 and 1971. In this study, specific combining ability by year interactions were significant for kernel weight but not for grain yield across both generations. Specific combining ability by year interactions were significant for the F_2's but not for the F_3's for spike number. The presence of prominent combining ability by environment interaction suggested that combining ability estimates obtained from a given year and location were an expression of conditions manifested explicitly in that year and location, and consequently interpretations should be made in that context. Considering the grain yield data, general combining ability by year interactions were significant for both the F_2 and F_3 generations and considerably larger than the specific combining ability by year interactions. These results were similar to those reported by Beil and Atkins (3) in sorghum.

Since the design of the present study did not allow for the estimation of location interactions, the relative importance of genotype by location effects was not known. It should be remembered, therefore, that the combining ability estimates obtained in this study may be biased upwards by location interaction effects.

With regard to estimates of general combining ability effects of the individual parents, the variety, Ag, appeared to be the most promising for yield and yield components as indicated by the seven-parent diallel analysis. Furthermore, the fact that four of the six F_1 hybrids exhibiting significant high-parent heterosis had Ag as a parent supported the combining ability data. This would indicate Ag would be of considerable value in a hybrid wheat program. The results from the six-parent diallel study of F_2's and F_3's revealed, however, that the parent, Sut, was the best combiner. The general combining ability effects for Sut were prominent in the F_3 generation for spike number, kernel weight and grain yield. Based on the two year average, the four highest yeidling F_3 hybrids had Sut as a parent suggesting that it would be of value in a conventional wheat breeding program. Regarding the prominent general combining ability effects of Ag and Sut for yield and yield components obtained in this study, it was of interest to note that OK696731, a selection from a 5*Sut/Ag backcross series was the highest yielding entry in Oklahoma performance trials in 1971 and 1972. Also, this selection, along with other Sut/Ag lines, had an excellent yield record in regional tests in 1972 (41).

Experiments conducted with barley (21,44) and wheat (19) have indicated that yield data obtained from bulk populations in the early segregation generations can be used to predict crosses from which a high proportion of high yielding segregates can be extracted. The results from the prediction phase of the present study showed good correlations between the midparent value and the F_3 generation and between the F_2 and the F_3 generations for yield. This indicated that the performance of parents and F_2 bulks would be useful in predicting the potential of F_3 bulk populations. Correlations for yield between the midparent value and the F_1 and between the midparent and the F_2 were quite low indicating that parental performance would not be a good indicator of F_1 and the F_2 performance. Correlations for yield between the F_1 and the F_2 generations in this study, although statistically significant appeared to be too low to be used reliably for predictive purposes. A high degree of association for heading dates between the F_1 and the F_2 and between the F_2 and F_3 bulk hybrids justifies selection for this trait among F_1 hybrids and among F_2 populations.

Based on the results of this study it would appear that yield trials of bulk populations in the F_2 generation, properly replicated and conducted in several places in the region would provide a reliable indication of the potential value of crosses in the F_3 generation. Such yield trials could be used for identifying promising crosses since the proportion of high-yielding genotypes in the low-yielding crosses will be less than in crosses with a higher average yield. Such a method of testing the relative potential value of several crosses would be most valuable when the bulk method of breeding is to be used during the early segregating generations. Single plant selections made in later generation should result in a high proportion of true-breeding, high-yielding strains.

CHAPTER VI

CONCLUSIONS

On the basis of this study the following conclusions are made.

(1) Sufficient levels of heterosis for grain yield occurred in certain combinations and thus indicates that further work on hybrid wheat would be warranted.

(2) Inbreeding depression for yield and yield components was related to the degree of heterosis. The utilization of the F_2 as the commercial crop does not appear to be justified especially if cytoplasmic male sterile and genetic restorer systems are involved.

(3) Kernel weight appeared to be the yield component primarily responsible for heterosis and inbreeding depression for grain yield.

(4) The combining ability analyses indicated that the genetic system for all characters measured was largely additive.

(5) On the basis of general combining ability effects for yield and yield components, Ag and Sut appeared to be the most promising parents.

(6) The presence of prominent combining ability x year interaction variances suggested that combining ability estimates obtained from a single test may be biased upward.

(7) The prediction study indicated that the midparent value and the F_2 would be useful in identifying potentially valuable F_3 bulk populations.

CHAPTER VII

SUMMARY

Heterosis and inbreeding depression, combining ability, and association between generations for heading date, plant height, yield and certain yield components were examined in two different diallel crossing systems of hard red winter wheat varieties. The first system, a seven-parent diallel cross was studied at Stillwater in the F_1 and F_2 generations in hill-plots arranged in a 7 x 7 lattice design with 8 replicates in 1969. The second system, a six-parent diallel cross, derived from the first system, was also studied at Stillwater in the F_2 and F_3 generations in nursery plots arranged in a 6 x 6 lattice design with 6 replicates in 1970 and 1971. Each plot was 3 m long and consisted of two rows 30 cm apart.

In the seven-parent diallel cross, the F_1 hybrids, in general, were similar to the midparent for heading date, but tended to be as tall as the taller parent. Six of 21 F_1 hybrids showed significant high-parent heterosis for yield. Five of these six hybrids also exhibited significant high-parent heterosis for kernel weight, indicating that kernel weight was the component primarily responsible for heterosis for yield. The performance of the F_1's for grain yield ranged from 78 to 140% of the high-parent values with a mean for all F_1's of 111%. The best F_1 hybrid, Ag/7654, had the largest spike number and also exhibited the greatest high-parent heterosis for yield. Significant high-parent heterosis was observed in several F_1 hybrids for spike number and kernel weight. No F_1 hybrid showed significant high-parent heterosis for kernels/spike, although several showed significant midparent heterosis for this trait.

The F_1 hybrids showing the greatest degree of heterosis for yield and yield components tended to exhibit the greatest degree of inbreeding depression in the F_2. Five of the six hybrids exhibiting significant inbreeding depression for yield also exhibited significant inbreeding depression for kernel weight, indicating that kernel weight was the component primarily associated with inbreeding depression for yield. Inbreeding depression for the 21 hybrids averaged 9% for yield, while the three hybrids which yielded significantly higher than the best check varieties had an average inbreeding depression value of 22%. The average inbreeding depression for the 21 hybrids was 10 and 8% for spike number and kernel weight, respectively. The value for kernels/spike was slightly higher in the F_2 than in the F_1.

In the six-parent diallel cross, the means of the 15 F_2 hybrids were similar to the high-parent mean for yield and kernel weight while the means for yield and kernel weight of the 15 F_3 hybrids were similar to the midparent values when averaged over two years. For spike number, however, the means of the 15 hybrids in both the F_2 and F_3 generations were similar to their midparent values in both years. Positive midparent deviations were found in several F_2 and F_3 hybrids for spike number, kernel weight, and yield in each year but in most cases these deviations were not significant.

The combining ability analyses from both diallel systems indicated that the genetic system for all characters measured was largely additive. The combined analysis indicated the presence of prominent combining ability by year interaction variances. This suggests that combining ability estimates obtained from a single test may be biased upward.

Ag had the most promising general combining ability effects for yield and yield components in the seven-parent diallel analysis while Sut was the most promising in the six-parent diallel analysis. Based on both tests, the Ag/7654 hybrid consistently had positive specific combining ability effects for grain yield while the Sut/7654 and 7654/Cmn hybrids consistently had negative effects for this trait.

The prediction study from both tests indicated that the midparent values were not correlated with the F_1 for yield. However, some degree of correlation was observed between midparent value and the F_2 and a good correlation was found between the midparent value and the F_3 for this trait. Some degree of correlation for yield was found between the F_1 and F_2 and a good correlation was found between the F_2 and F_3 generation.

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APPENDIX

TABLE XVII

MEAN SQUARES FROM THE ANALYSIS OF VARIANCE OF A SEVEN-PARENT DIALLEL CROSS INCLUDING PARENTS, F_1'S AND F_2'S, 1969

Source of Variation	d.f.	Heading Date	Plant Height	Spike Number	Kernel Weight	Kernels/Spike	Grain Yield
Replications	7	40.142**	289.537*	169.099**	0.725	34.633*	110.422*
Genotypes (P, F_1, F_2)	48	167.114**	1833.383**	124.364**	9.811**	231.422**	284.118**
Experimental Error	336	3.229	117.795	46.061	0.448	16.045	49.171
Sampling Error	1176	1.651	80.062	9.627	0.120	6.862	12.358

*Significant at 5% level. **Significant at 1% level.

TABLE XVIII

PARENTAL, F_1 AND F_2 MEANS, MULTIPLE RANGE COMPARISONS FOR HEADING DATE FROM SEVEN-PARENT DIALLEL CROSS, 1969

Pedigree	Generation	Rank (earliest to latest)	Heading Date[1]	
Tmp 64/7654	F_2	1	29.7	a
7654/Danne	F_2	2	30.4	ab
Tmp 64/Sdy	F_2	3	30.5	ab
Sut/Tmp 64	F_2	4	30.5	ab
Sut/Danne	F_2	5	30.7	bc
Sdy/Cmn	F_2	6	31.0	bcd
Sut/Sdy	F_2	7	31.0	bcd
Danne	P	8	31.1	bcd
Tmp 64	P	9	31.2	bcd
Tmp 64/Sdy	F_1	10	31.2	bcde
Sdy/Danne	F_1	11	31.2	bcde
Tmp 64/7654	F_1	12	31.3	bcde
Sut/Danne	F_2	13	31.4	bcde
Tmp 64/Danne	F_1	14	31.5	cdef
Sut/Tmp 64	F_1	15	31.6	cdef
Ag/Sdy	F_2	16	31.7	defg
Tmp 64/Danne	F_2	17	31.7	defg
Sdy	P	18	31.8	defg
7654/Sdy	F_1	19	31.8	defg
7654/Sdy	F_2	20	31.9	defg
Sut/Sdy	F_1	21	32.0	defg
7654/Danne	F_1	22	32.1	defgh
Tmp 64/Ag	F_2	23	32.1	efgh
Tmp 64/Cmn	F_2	24	32.2	efgh
Ag/Sdy	F_1	25	32.3	fgh
7654	P	26	32.3	fgh
Tmp 64/Cmn	F_1	27	32.4	fgh
Cmn/Danne	F_1	28	32.5	fgh
Sdy/Cmn	F_1	29	32.5	gh
Cmn/Danne	F_2	30	32.7	gh
Tmp 64/Ag	F_1	31	32.9	hi
Sut/Danne	F_1	32	33.1	hi
7654/Cmn	F_2	33	33.5	ij
Ag/Danne	F_2	34	33.7	ij
Sut/7654	F_2	35	34.1	jk
Ag/Danne	F_1	36	34.3	jk
Sut	P	37	34.7	kl
Ag/7654	F_2	38	35.3	lm
Sut/7654	F_1	39	35.7	mn
7654/Cmn	F_1	40	35.9	mno
Sut/Cmn	F_1	41	36.0	mno
Sut/Cmn	F_2	42	36.2	no
Sut/Ag	F_2	43	36.3	no
Sut/Ag	F_1	44	36.7	op
Ag/7654	F_1	45	36.9	op
Cmn	P	46	36.9	op
Ag/Cmn	F_1	47	37.4	p
Ag/Cmn	F_2	48	37.5	p
Ag	P	49	38.7	q

[1] Number of days after April 1st.

Note: Those means not followed by the same letter are significantly different at P = .05; means followed by the same letter are not significantly different at P = .05.

TABLE XIX

PARENTAL, F_1 AND F_2 MEANS, MULTIPLE RANGE COMPARISONS FOR PLANT HEIGHT FROM SEVEN-PARENT DIALLEL CROSS, 1969

Pedigree	Generation	Rank (shortest to tallest)	Plant Height (cm)	
Sdy	P	1	80.1	a
Tmp 64/Sdy	F_1	2	95.6	b
Tmp 64/Sdy	F_2	3	96.7	b
Sdy/Danne	F_1	4	96.9	b
Sut/Sdy	F_1	5	98.4	bc
Sdy/Cmn	F_1	6	98.5	bc
Sut/Sdy	F_2	7	99.6	bcd
7654/Sdy	F_1	8	99.8	bcde
Danne	P	9	100.6	bcdef
Tmp 64/Danne	F_2	10	101.2	bcdef
Sut/Danne	F_1	11	101.3	bcdef
Ag/Sdy	F_1	12	104.1	cdefg
Sdy/Danne	F_2	13	104.1	cdefg
Tmp 64/Danne	F_1	14	104.2	cdefg
Tmp 64	P	15	104.6	cdefgh
Ag/Sdy	F_2	16	104.6	cdefgh
Sut/Tmp 64	F_1	17	104.8	cdefgh
Sut	P	18	105.0	defgh
7654/Danne	F_1	19	105.3	defghi
Tmp 64/Cmn	F_1	20	105.4	defghi
7654	P	21	105.8	defghi
Tmp 64/7654	F_1	22	106.3	efghij
Sdy/Cmn	F_2	23	106.8	fghijk
Sut/Danne	F_2	24	107.8	ghijkl
Cmn/Danne	F_1	25	108.1	ghijkl
7654/Sdy	F_2	26	108.4	ghijkl
Ag/Danne	F_2	27	108.6	ghijkl
Tmp 64/Ag	F_2	28	108.7	ghijkl
7654/Cmn	F_2	29	109.1	ghijkl
Tmp 64/Ag	F_1	30	109.1	ghijkl
Ag/Danne	F_1	31	109.2	ghijkl
7654/Danne	F_2	32	109.8	ghijkl
Sut/Tmp 64	F_2	33	110.0	ghijkl
Sut/7654	F_1	34	111.0	hijklm
Tmp 64/Cmn	F_2	35	111.6	hijklm
Sut/7654	F_2	36	111.7	hijklm
Tmp 64/Cmn	F_2	37	111.9	ijklmn
Sut/Ag	F_2	38	112.9	jklmn
Ag	P	39	112.9	jklmn
Cmn/Danne	F_2	40	112.9	klmn
Cmn	P	41	113.2	klmn
Sut/Cmn	F_1	42	114.0	lmno
Ag/7654	F_2	43	116.3	mno
Ag/Cmn	F_2	44	116.8	mnop
Sut/Ag	F_1	45	118.1	nop
Ag/Cmn	F_1	46	118.3	op
Sut/Cmn	F_1	47	118.9	op
Ag/7654	F_1	48	119.0	op
7654/Cmn	F_1	49	122.7	p

Note: Those means not followed by the same letter are significantly different at P = .05; means followed by the same letter are not significantly different at P = .05.

TABLE XX

PARENTAL, F_1 AND F_2 MEANS, MULTIPLE RANGE COMPARISONS FOR SPIKE NUMBER FROM SEVEN-PARENT DIALLEL CROSS, 1969

Pedigree	Generation	Rank (highest to lowest)	Spike Number	
Ag/7654	F_1	1	32.47	a
Sut/Cmn	F_1	2	31.56	ab
Ag/Cmn	F_1	3	31.34	abc
Sut/7654	F_1	4	30.78	abcd
Tmp 64/Cmn	F_1	5	30.69	abcde
Tmp 64/7654	F_1	6	30.59	abcde
Cmn/Danne	F_1	7	30.38	abcdef
Sut/Ag	F_1	8	30.00	abcdefg
Tmp 64	P	9	29.53	abcdefgh
Sut/Tmp 64	F_1	10	29.50	abcdefgh
Ag/7654	F_2	11	28.84	abcdefghi
Tmp 64/Ag	F_1	12	28.84	abcdefghi
7654/Cmn	F_1	13	28.78	abcdefghi
Sut/Cmn	F_2	14	28.75	abcdefghi
Cmn	P	15	28.65	abcdefghi
Tmp 64/7654	F_2	16	28.44	abcdefghij
Sut	P	17	28.38	abcdefghij
Sut/Tmp 64	F_2	18	28.22	bcdefghij
Ag/Cmn	F_2	19	28.16	bcdefghij
Tmp 64/Danne	F_1	20	27.97	bcdefghij
Sut/7654	F_2	21	27.88	bcdefghij
Ag	P	22	27.69	bcdefghij
Cmn/Danne	F_2	23	27.69	bcdefghij
Sut/Danne	F_2	24	27.66	bcdefghij
Sdy/Cmn	F_1	25	27.59	bcdefghij
7654/Sdy	F_2	26	27.47	bcdefghij
7654	P	27	27.44	bcdefghij
Ag/Danne	F_1	28	27.34	cdefghij
Sut/Sdy	F_1	29	27.25	cdefghij
Sdy/Danne	F_1	30	27.19	cdefghij
7654/Cmn	F_2	31	27.19	cdefghij
Tmp 64/Cmn	F_2	32	27.16	defghij
7654/Danne	F_1	33	27.16	defghij
Tmp 64/Danne	F_2	34	27.06	defghij
Ag/Sdy	F_1	35	26.88	defghij
Sut/Ag	F_2	36	26.75	defghij
Sdy/Cmn	F_2	37	26.53	efghijk
Danne	P	38	26.34	fghijk
7654/Danne	F_2	39	26.16	ghijk
Tmp 64/Ag	F_2	40	26.13	ghijk
Sdy/Danne	F_2	41	26.00	ghijk
Tmp 64/Sdy	F_1	42	25.75	hijk
Ag/Danne	F_2	43	25.50	hijk
7654/Sdy	F_1	44	25.43	hijk
Ag/Sdy	F_2	45	25.43	ijk
Sut/Sdy	F_2	46	25.16	ijk
Sdy	P	47	25.16	ijk
Tmp 64/Sdy	F_2	48	24.38	jk
Sut/Danne	F_1	49	22.69	k

Note: Those means not followed by the same letter are significantly different at P = .05; means followed by the same letter are not significantly different at P = .05.

TABLE XXI

PARENTAL, F_1 AND F_2 MEANS, MULTIPLE RANGE COMPARISONS FOR KERNEL WEIGHT FROM SEVEN-PARENT DIALLEL CROSS, 1969

Pedigree	Generation	Rank (highest to lowest)	Kernel Weight	
Sut/Tmp 64	F_1	1	7.58	a
Tmp 64/Ag	F_1	2	7.49	a
Tmp 64/Cmn	F_1	3	7.24	ab
Tmp 64/7654	F_1	4	7.13	b
Sdy/Danne	F_1	5	7.05	bc
Sut/Ag	F_1	6	7.04	bc
Tmp 64/Sdy	F_1	7	7.04	bc
Tmp 64	P	8	6.99	bcd
7654/Sdy	F_1	9	6.98	bcd
Sut/Sdy	F_1	10	6.96	bcd
Tmp 64/Danne	F_1	11	6.95	bcd
Ag/Sdy	F_1	12	6.94	bcd
Sut/Danne	F_2	13	6.73	cde
Ag/Cmn	F_1	14	6.73	cde
Sdy/Cmn	F_1	15	6.73	cde
Cmn/Danne	F_1	16	6.68	cdef
7654/Danne	F_2	17	6.68	cdef
Ag/7654	F_1	18	6.66	cdef
Tmp 64/Ag	F_2	19	6.65	cdefg
Sut/Sdy	F_2	20	6.59	defgh
Sut/Cmn	F_1	21	6.55	efgh
Danne	P	22	6.54	efgh
Tmp 64/Cmn	F_2	23	6.54	efgh
Sdy/Cmn	F_2	24	6.47	efghi
Sut/Tmp 64	F_2	25	6.45	efghij
Sut/Ag	F_2	26	6.42	efghij
Tmp 64/7654	F_2	27	6.41	efghijk
Sdy/Danne	F_2	28	6.40	efghijk
Tmp 64/Sdy	F_2	29	6.37	efghijk
Sut	P	30	6.34	efghijkl
Tmp 64/Danne	F_2	31	6.31	fghijklm
7654	P	32	6.25	ghijklmn
7654/Danne	F_1	33	6.23	hijklmn
Sut/Danne	F_1	34	6.22	hijklmn
7654/Sdy	F_2	35	6.21	hijklmn
7654/Cmn	F_2	36	6.09	ijklmno
Ag/Sdy	F_2	37	6.07	ijklmnop
Sut/7654	F_1	38	6.06	jklmnop
Ag/7654	F_2	39	6.01	klmnop
Cmn/Danne	F_2	40	5.97	lmnop
7654/Cmn	F_1	41	5.93	mnopq
Sut/7654	F_2	42	5.87	nopqr
Sdy	P	43	5.71	opqrs
Ag/Danne	F_1	44	5.68	pqrs
Cmn	P	45	5.58	qrs
Ag/Danne	F_2	46	5.53	rs
Ag	P	47	5.44	s
Sut/Cmn	F_2	48	5.44	s
Ag/Cmn	F_2	49	5.06	t

Note: Those means not followed by the same letter are significantly different at $P = .05$; means followed by the same letter are not significantly different at $P = .05$.

TABLE XXII

PARENTAL, F_1 AND F_2 MEANS, MULTIPLE RANGE COMPARISONS FOR KERNELS PER SPIKE FROM SEVEN-PARENT DIALLEL CROSS, 1969

Pedigree	Generation	Rank (highest to lowest)	Kernels/Spike	
Ag/Cmn	F_2	1	36.0	a
Ag/Danne	F_2	2	35.4	ab
Cmn/Danne	F_2	3	35.1	abc
Ag/Danne	F_1	4	34.9	abcd
Ag/Sdy	F_2	5	34.1	abcde
Ag	P	6	33.8	bcde
Ag/7654	F_1	7	33.0	cdef
Ag/7654	F_2	8	32.9	cdef
Sut/Cmn	F_2	9	32.8	defg
Ag/Sdy	F_1	10	32.8	defg
Ag/Cmn	F_1	11	32.2	efgh
Sdy	P	12	32.1	efgh
7654/Danne	F_1	13	32.1	efgh
Tmp 64/Sdy	F_2	14	31.7	fghi
Sdy/Danne	F_1	15	31.4	fghij
Sdy/Danne	F_2	16	32.3	fghij
7654/Sdy	F_1	17	31.3	fghijk
Sdy/Cmn	F_2	18	31.1	fghijkl
Sut/Ag	F_1	19	30.8	fghijklm
Tmp 64/Danne	F_2	20	30.8	fghijklm
Danne	P	21	30.5	ghijklmn
7654/Sdy	F_2	22	30.5	ghijklmn
Cmn/Danne	F_1	23	30.5	ghijklmn
Sdy/Cmn	F_1	24	30.3	hijklmno
7654/Danne	F_2	25	30.2	hijklmnop
Sut/Ag	F_2	26	29.9	hijklmnopq
Tmp 64/Sdy	F_1	27	29.8	hijklmnopq
Sut/Tmp 64	F_2	28	29.6	ijklmnopq
7654/Cmn	F_1	29	29.6	ijklmnopq
Tmp 64/Danne	F_1	30	29.4	ijklmnopq
7654	P	31	29.4	ijklmnopq
Sut/Danne	F_1	32	29.4	ijklmnopq
Tmp 64/7654	F_2	33	29.3	ijklmnopq
Sut/Sdy	F_2	34	29.1	jklmnopq
Tmp 64/Ag	F_1	35	28.8	klmnopq
Tmp/Ag	F_2	36	28.7	lmnopqr
Sut/Sdy	F_1	37	28.6	mnopqr
7654/Cmn	F_2	38	28.3	nopqrs
Sut/7654	F_2	39	28.2	nopqrs
Cmn	P	40	28.0	opqrst
Tmp 64/Cmn	F_2	41	27.8	pqrst
Tmp 64/7654	F_1	42	27.7	qrst
Sut/Danne	F_2	43	27.7	qrst
Tmp 64/Cmn	F_1	44	27.5	qrst
Sut	P	45	26.3	rstu
Tmp 64	P	46	26.0	stu
Sut/Cmn	F_1	47	25.8	tu
Sut/7654	F_1	48	24.9	u
Sut/Tmp 64	F_1	49	24.2	u

Note: Those means not followed by the same letter are significantly different at $P = .05$; means followed by the same letter are not significantly different at $P = .05$.

TABLE XXIII

PARENTAL, F_1 AND F_2 MEANS, MULTIPLE RANGE COMPARISONS FOR GRAIN YIELD FROM SEVEN-PARENT DIALLEL CROSS, 1969

Pedigree	Generation	Rank (highest to lowest)	Grain Yield (gms)	
Ag/7654	F_1	1	35.6	a
Ag/Cmn	F_1	2	33.7	ab
Sut/Ag	F_1	3	32.7	abc
Cmn/Danne	F_1	4	31.1	bcd
Tmp 64/Ag	F_1	5	31.1	bcd
Tmp 64/Cmn	F_1	6	30.6	bcde
Ag/Sdy	F_1	7	30.3	bcdef
Sdy/Danne	F_1	8	30.1	bcdefg
Tmp 64/7654	F_1	9	30.0	bcdefgh
Cmn/Danne	F_2	10	28.7	cdefghi
Tmp 64/Danne	F_1	11	28.4	defghi
Ag/7654	F_2	12	28.4	defghi
Sdy/Cmn	F_1	13	28.1	defghij
7654/Sdy	F_1	14	27.7	defghijk
Ag/Danne	F_1	15	27.1	defghijkl
Sut/Sdy	F_1	16	27.1	defghijkl
Sut/Tmp 64	F_1	17	26.9	defghijkl
Tmp 64/Sdy	F_1	18	26.9	defghijkl
Tmp 64	P	19	26.9	defghijkl
Sut/Tmp 64	F_2	20	26.9	defghijkl
7654/Danne	F_1	21	26.8	defghijkl
Sut/Cmn	F_1	22	26.6	efghijkl
Sdy/Cmn	F_2	23	26.5	efghijklm
7654/Danne	F_2	24	26.5	efghijklm
Danne	P	25	26.2	fghijklm
Ag/Sdy	F_2	26	26.2	fghijklm
Tmp 64/7654	F_2	27	26.1	fghijklm
Tmp 64/Danne	F_2	28	26.1	fghijklm
Sdy/Danne	F_2	29	26.0	ghijklm
7654/Sdy	F_2	30	25.7	hijklm
Ag/Cmn	F_2	31	25.7	hijklm
Sut/Cmn	F_2	32	25.6	ijklm
Sut/Danne	F_2	33	25.5	ijklm
Ag	P	34	25.5	ijklm
Sut/Ag	F_2	35	25.4	ijklm
7654/Cmn	F_1	36	25.2	ijklm
Ag/Danne	F_2	37	25.0	ijklm
7654	P	38	25.0	ijklm
Tmp 64/Ag	F_2	39	24.9	ijklm
Tmp 64/Cmn	F_2	40	24.7	ijklmn
Tmp 64/Sdy	F_2	41	24.4	ijklmn
Sut/Sdy	F_2	42	23.9	jklmn
Sut	P	43	23.7	klmn
Sut/7654	F_1	44	23.0	lmn
Sut/7654	F_2	45	22.9	lmn
7654/Cmn	F_2	46	22.9	lmn
Sdy	P	47	22.9	lmn
Cmn	P	48	22.3	mn
Sut/Danne	F_1	49	20.7	n

Note: Those means not followed by the same letter are significantly different at P = .05; means followed by the same letter are not significantly different at P = .05.

TABLE XXIV

MEAN SQUARES FROM THE TWO-YEAR COMBINED ANALYSIS OF VARIANCE OF A SIX-PARENT DIALLEL CROSS INCLUDING PARENTS, F_2'S AND F_3'S, 1970 AND 1971

Source of Variation	d.f.	Spike Number	Kernel Weight	Grain Yield
Years	1	38184.681**	56.623**	772.273**
Reps in Years	5	130.510**	0.422	54.726**
Genotypes	35	123.798**	0.530**	53.776**
Years x Genotypes	35	122.810**	0.637**	61.067**
Error	175	46.314	0.306	15.311

*Significant at 5% level. **Significant at 1% level.

TABLE XXV

MEAN SQUARES FROM THE ANALYSIS OF VARIANCE OF A SIX-PARENT DIALLEL CROSS INCLUDING PARENTS, F_2'S AND F_3'S, 1970

Source of Variation	d.f.	Heading Date	Plant Height	Spike Number	Kernel Weight	Grain Yield
Replications	5	17.511**	158.508**	70.668	0.402**	55.276**
Genotypes	35	20.481**	74.804**	115.423**	0.500**	50.713**
Error	175	1.19	4.617	40.626	0.126	19.216

*Significant at 5% level. **Significant at 1% level.

TABLE XXVI

MEAN SQUARES FROM THE ANALYSIS OF VARIANCE OF A SIX-PARENT DIALLEL CROSS INCLUDING PARENTS, F_2'S AND F_3'S, 1971

Source of Variation	d.f.	Heading Date	Plant Height	Spike Number	Kernel Weight	Grain Yield
Replications	5	--	--	190.353**	0.441**	54.177**
Genotypes	35	--	--	131.185**	0.717**	64.130**
Error	175	--	--	51.901	0.053	11.405

*Significant at 5% level. **Significant at 1% level.

TABLE XXVII

PARENTAL, F_2 AND F_3 BULK MEANS, MULTIPLE RANGE COMPARISONS FOR HEADING DATE FROM SIX-PARENT DIALLEL CROSS, 1970

Pedigree	Generation	Rank (earliest to latest)	Heading Date[1]	
Tmp 64	P	1	27.2	a
Tmp 64/Sdy	F_2	2	28.2	ab
Sut/Tmp 64	F_3	3	28.2	ab
Tmp 64/7654	F_2	4	28.7	bc
Tmp 64/7654	F_3	5	28.8	bcd
Sut/Tmp 64	F_2	6	28.8	bcd
Sut/Sdy	F_2	7	29.0	bcde
Tmp 64/Sdy	F_3	8	29.7	cde
Tmp 64/Ag	F_2	9	29.7	cde
Tmp 64/Cmn	F_2	10	29.7	cde
Tmp 64/Cmn	F_3	11	29.8	cdef
Sut	P	12	29.8	cdef
Sdy/Cmn	F_2	13	30.0	cdef
Sut/Sdy	F_3	14	30.0	cdef
Sdy	P	15	30.0	cdef
7654/Sdy	F_2	16	30.2	def
Ag/Sdy	F_2	17	30.3	def
Tmp 64/Ag	F_3	18	30.3	def
7654/Sdy	F_3	19	30.3	def
Sut/7654	F_3	20	30.3	def
7654	P	21	30.5	ef
Ag/Sdy	F_3	22	31.3	fg
Sdy/Cmn	F_3	23	31.3	fg
Sut/7654	F_2	24	31.3	fg
Sut/Ag	F_3	25	31.3	fg
Sut/Cmn	F_2	26	32.2	gh
Sut/Ag	F_2	27	32.2	gh
Ag/7654	F_2	28	32.3	gh
Sut/Cmn	F_2	29	32.5	ghi
7654/Cmn	F_3	30	32.7	ghi
Ag/7654	F_3	31	32.7	hi
Ag	P	32	33.3	hij
7654/Cmn	F_2	33	33.3	hij
Ag/Cmn	F_2	34	33.8	ijk
Cmn	P	35	34.3	jk
Ag/Cmn	F_3	36	34.8	k

[1] Number of days after April 1st.

Note: Those means not followed by the same letter are significantly different at P = .05; means followed by the same letter are not significantly different at P = .05.

TABLE XXVIII

PARENTAL, F_2 AND F_3 BULK MEANS, MULTIPLE RANGE COMPARISONS FOR PLANT HEIGHT FROM SIX-PARENT DIALLEL CROSS, 1970

Pedigree	Generation	Rank (shortest to tallest)	Plant Height (cm)	
Sdy	P	1	82.5	a
Tmp 64	P	2	98.0	b
7654/Sdy	F_2	3	98.8	b
Sut/Sdy	F_3	4	99.3	b
Ag/Sdy	F_2	5	99.3	b
Tmp 64/7654	F_2	6	99.3	b
Tmp 64/7654	F_3	7	99.3	b
Tmp 64/Sdy	F_2	8	99.5	bc
Tmp 64/Ag	F_2	9	99.7	bc
Sut/7654	F_2	10	99.7	bc
Tmp 64/Sdy	F_3	11	99.8	bcd
Tmp 64/Cmn	F_3	12	100.0	bcd
7654	P	13	100.0	bcd
Ag/Sdy	F_3	14	100.3	bcde
Sut/Sdy	F_2	15	100.3	bcde
Sut/Tmp 64	F_3	16	100.5	bcde
Tmp 64/Cmn	F_2	17	100.7	bcde
7654/Sdy	F_3	18	100.8	bcde
Sut/Tmp 64	F_2	19	101.2	cdef
Cmn	P	20	101.2	cdef
Sut	P	21	101.2	cdef
Sdy/Cmn	F_2	22	101.3	cdef
Tmp 64/Ag	F_3	23	101.5	cdefg
7654/Cmn	F_3	24	101.5	cdefg
Sut/7654	F_3	25	101.5	cdefg
Ag/7654	F_2	26	102.0	cdefg
Sdy/Cmn	F_3	27	102.3	cdefgh
Ag/Cmn	F_2	28	102.3	cdefgh
Sut/Cmn	F_3	29	102.5	cdefgh
Sut/Ag	F_3	30	102.5	cdefgh
7654/Cmn	F_2	31	102.8	defgh
Ag/7654	F_3	32	103.3	efgh
Ag	P	33	104.0	fgh
Sut/Cmn	F_2	34	104.0	fgh
Ag/Cmn	F_3	35	104.3	gh
Sut/Ag	F_2	36	105.0	h

Note: Those means not followed by the same letter are significantly different at $P = .05$; means followed by the same letter are not significantly different at $P = .05$.

TABLE XXIX

PARENTAL, F_2 AND F_3 BULK MEANS, MULTIPLE RANGE COMPARISONS FOR NUMBER OF SPIKES FROM SIX-PARENT DIALLEL CROSS, 1970

Pedigree	Generation	Rank (highest to lowest)	Spike Number	
Tmp 64/7654	F_2	1	70.4	a
Sut/Tmp 64	F_2	2	69.5	ab
Sut	P	3	68.8	abc
Sut/Ag	F_2	4	68.7	abcd
Sut/Tmp 64	F_3	5	68.1	abcde
Tmp 64/Sdy	F_3	6	67.0	abcdef
Sut/Ag	F_3	7	65.8	abcdefg
Ag/7654	F_2	8	63.8	abcdefg
Sut/Sdy	F_2	9	63.7	abcdefgh
Sut/7654	F_3	10	63.3	abcdefgh
Sut/Cmn	F_2	11	63.2	abcdefgh
Sdy/Cmn	F_2	12	63.1	abcdefgh
Ag	P	13	62.9	abcdefgh
7654/Sdy	F_3	14	62.8	abcdefgh
7654	P	15	62.6	abcdefgh
7654/Cmn	F_2	16	62.4	abcdefgh
Tmp 64	P	17	60.9	bcdefghi
Tmp 64/7654	F_3	18	60.8	bcdefghi
Tmp 64/Ag	F_3	19	60.7	bcdefghi
7654/Sdy	F_2	20	60.5	cdefghi
Ag/7654	F_3	21	60.3	cdefghi
Sut/Cmn	F_3	22	59.9	defghi
7654/Cmn	F_3	23	59.8	efghi
Tmp 64/Sdy	F_2	24	59.7	efghi
Tmp 64/Cmn	F_2	25	59.4	efghi
Cmn	P	26	59.2	efghi
Sut/7654	F_2	27	59.2	efghi
Tmp 64/Ag	F_2	28	59.1	efghi
Tmp 64/Cmn	F_3	29	58.2	fghi
Ag/Sdy	F_2	30	57.8	ghi
Ag/Cmn	F_2	31	57.8	ghi
Sut/Sdy	F_3	32	57.1	ghi
Sdy/Cmn	F_3	33	55.8	hi
Ag/Sdy	F_3	34	55.3	hi
Ag/Cmn	F_3	35	53.2	i
Sdy	P	36	52.9	i

Note: Those means not followed by the same letter are significantly different at P = .05; means followed by the same letter are not significantly different at P = .05.

TABLE XXX

PARENTAL, F_2 AND F_3 BULK MEANS, MULTIPLE RANGE COMPARISONS FOR KERNEL WEIGHT FROM SIX-PARENT DIALLEL CROSS, 1970

Pedigree	Generation	Rank (highest to lowest	Kernel Weight	
Tmp 64	P	1	5.53	a
Tmp 64/Cmn	F_2	2	5.45	ab
Tmp 64/Sdy	F_2	3	5.40	abc
Sut/Tmp 64	F_2	4	5.38	abcd
Tmp 64/Ag	F_3	5	5.35	abcde
Sut/Cmn	F_2	6	5.33	abcdef
Sut/Tmp 64	F_3	7	5.32	abcdefg
Sut/Ag	F_2	8	5.22	abcdefgh
Sut	P	9	5.22	abcdefgh
Tmp 64/Ag	F_2	10	5.22	abcdefgh
Sut/7654	F_3	11	5.20	abcdefghi
Tmp 64/7654	F_3	12	5.20	abcdefghi
Sut/Cmn	F_3	13	5.10	abcdefghij
Sut/7654	F_2	14	5.07	abcdefghij
Tmp 64/7654	F_2	15	5.05	abcdefghij
Ag/Cmn	F_2	16	5.03	bcdefghij
Ag/7654	F_3	17	5.03	bcdefghij
Sut/Sdy	F_3	18	4.97	bcdefghijk
Sut/Sdy	F_2	19	4.95	cdefghijk
7654/Sdy	F_3	20	4.92	cdefghijk
Tmp 64/Cmn	F_3	21	4.92	cdefghijk
Ag/Sdy	F_3	22	4.88	defghijk
Sdy/Cmn	F_3	23	4.88	defghijk
Sdy/Cmn	F_2	24	4.85	efghijk
7654/Cmn	F_2	25	4.83	fghijk
Ag/7654	F_2	26	4.82	ghijk
Ag	P	27	4.82	ghijk
Cmn	P	28	4.77	hijk
Tmp 64/Sdy	F_3	29	4.77	hijk
Sut/Ag	F_3	30	4.73	hijk
Ag/Sdy	F_2	31	4.73	hijk
Ag/Cmn	F_3	32	4.70	ijk
7654/Sdy	F_2	33	4.63	jk
7654	P	34	4.60	jk
7654/Cmn	F_3	35	4.60	k
Sdy	P	36	4.50	k

Note: Those means not followed by the same letter are significantly different at P = .05; means followed by the same letter are not significantly different at P = .05.

TABLE XXXI

PARENTAL, F_2 AND F_3 BULK MEANS, MULTIPLE RANGE COMPARISONS FOR GRAIN YIELD FROM SIX-PARENT DIALLEL CROSS, 1970

Pedigree	Generation	Rank (highest to lowest)	Grain Yield (gms)	
Tmp 64/Sdy	F_2	1	440	a
Sut/Ag	F_2	2	430	ab
Sut	P	3	429	ab
Tmp 64	P	4	412	abc
Sut/Sdy	F_2	5	408	abcd
Sut/Cmn	F_2	6	400	abcd
Sut/Tmp 64	F_3	7	399	abcde
Ag/7654	F_2	8	395	abcdef
Tmp 64/7654	F_2	9	392	abcdefg
Tmp 64/7654	F_3	10	390	abcdefg
Sut/Tmp 64	F_2	11	388	abcdefg
Sut/Cmn	F_3	12	386	abcdefg
Sdy/Cmn	F_2	13	386	abcdefg
7654/Sdy	F_2	14	381	abcdefgh
Sut/7654	F_2	15	381	abcdefgh
Tmp 64/Ag	F_2	16	377	bcdefgh
Sut/7654	F_3	17	376	bcdefgh
Tmp 64/Sdy	F_3	18	376	bcdefgh
Tmp 64/Ag	F_3	19	375	bcdefgh
Ag	P	20	373	bcdefgh
Tmp 64/Cmn	F_2	21	373	bcdefgh
Tmp 64/Cmn	F_3	22	372	bcdefgh
Sut/Ag	F_3	23	372	bcdefgh
7654/Sdy	F_3	24	370	cdefgh
Sdy/Cmn	F_3	25	361	cdefgh
Ag/Cmn	F_2	26	356	cdefgh
Sdy	P	27	352	cdefgh
Sut/Sdy	F_3	28	351	cdefgh
7654/Cmn	F_2	29	350	cdefgh
Ag/7654	F_3	30	348	defgh
7654/Cmn	F_3	31	348	defgh
Cmn	P	32	337	efgh
7654	P	33	336	fgh
Ag/Cmn	F_3	34	331	gh
Ag/Sdy	F_2	35	322	h
Ag/Sdy	F_3	36	322	h

Note: Those means not followed by the same letter are significantly different at P = .05; means followed by the same letter are not significantly different at P = .05.

TABLE XXXII

PARENTAL, F_2 AND F_3 BULK MEANS, MULTIPLE RANGE COMPARISONS FOR NUMBER OF SPIKES FROM SIX-PARENT DIALLEL CROSS, 1971

Pedigree	Generation	Rank (highest to lowest)	Spike Number	
Ag/7654	F_3	1	52.5	a
Sut/7654	F_3	2	50.3	ab
Sut/Tmp 64	F_3	3	50.3	ab
Sut/Cmn	F_2	4	48.9	abc
Ag/7654	F_2	5	48.9	abc
7654/Cmn	F_2	6	48.5	abc
Cmn	P	7	47.2	abcd
Sut	P	8	46.0	abcd
Tmp 64/Ag	F_2	9	46.8	abcde
7654/Cmn	F_3	10	45.6	abcde
Ag/Cmn	F_2	11	45.5	abcde
Sut/Cmn	F_3	12	45.3	abcde
Ag/Sdy	F_3	13	44.8	abcde
7654/Sdy	F_3	14	44.0	abcde
Ag	P	15	43.6	abcde
Tmp 64	P	16	42.7	abcde
Tmp 64/7654	F_3	17	42.7	abcde
Sut/Tmp 64	F_2	18	42.0	bcde
Sut/Sdy	F_3	19	41.9	bcde
Sut/Ag	F_3	20	41.7	bcde
Tmp 64/Cmn	F_2	21	41.0	bcde
7654	P	22	40.8	bcde
Sut/Sdy	F_2	23	40.8	bcde
Sdy/Cmn	F_2	24	40.7	bcde
Ag/Cmn	F_3	25	40.1	cdef
Tmp 64/Sdy	F_3	26	40.1	cdef
Ag/Sdy	F_2	27	40.0	cdef
Sut/Ag	F_2	28	40.0	cdef
Tmp 64/Cmn	F_3	29	39.5	cdef
Tmp 64/Sdy	F_2	30	38.3	def
Tmp 64/7654	F_2	31	38.2	def
Sut/7654	F_2	32	37.7	def
7654/Sdy	F_2	33	37.7	def
Tmp 64/Ag	F_2	34	37.5	def
Sdy	P	35	35.8	ef
Sdy/Cmn	F_3	36	30.4	f

Note: Those means not followed by the same letter are significantly different at P = .05; means followed by the same letter are not significantly different at P = .05.

TABLE XXXIII

PARENTAL, F_2 AND F_3 BULK MEANS, MULTIPLE RANGE COMPARISONS FOR KERNEL WEIGHT FROM SIX-PARENT DIALLEL CROSS, 1971

Pedigree	Generation	Rank (highest to lowest	Kernel Weight	
Sut/Tmp 64	F_2	1	6.55	a
Sut	P	2	6.22	b
Tmp 64/Cmn	F_3	3	6.18	b
Sut/Sdy	F_2	4	6.15	bc
Sut/Ag	F_2	5	6.10	bcd
Sut/Tmp 64	F_3	6	6.10	bcd
Tmp 64/Cmn	F_2	7	6.10	bcd
Tmp 64/7654	F_2	8	6.03	bcde
Sut/Cmn	F_2	9	6.00	bcde
Sut/7654	F_2	10	6.00	bcde
Sut/Ag	F_3	11	5.87	cdef
Tmp 64	P	12	5.83	def
7654/Sdy	F_2	13	5.83	def
Sut/Sdy	F_3	14	5.82	def
Tmp 64/Ag	F_2	15	5.82	def
Tmp 64/Sdy	F_3	16	5.78	efg
Sut/7654	F_3	17	5.78	efg
Tmp 64/Ag	F_3	18	5.77	efg
Sut/Cmn	F_3	19	5.75	efg
Cmn	P	20	5.75	efg
Ag/Cmn	F_2	21	5.68	fgh
7654/Cmn	F_2	22	5.65	fgh
Tmp 64/Sdy	F_2	23	5.62	fghi
Ag/Sdy	F_2	24	5.57	fghij
Sdy	P	25	5.50	ghijk
Ag/Cmn	F_3	26	5.48	ghijk
7654/Sdy	F_3	27	5.47	ghijk
7654	P	28	5.47	ghijk
Ag/7654	F_2	29	5.47	ghijk
Sdy/Cmn	F_2	30	5.40	hijk
Tmp 64/7654	F_3	31	5.33	ijkl
Sdy/Cmn	F_3	32	5.30	jklm
Ag/Sdy	F_3	33	5.28	jklm
Ag/7654	F_3	34	5.20	klm
7654/Cmn	F_3	35	5.10	lm
Ag	P	36	5.03	m

Note: Those means not followed by the same letter are significantly different at P = .05; means followed by the same letter are not significantly different at P = .05.

TABLE XXXIV

PARENTAL, F_2 AND F_3 BULK MEANS, MULTIPLE RANGE COMPARISONS FOR GRAIN YIELD FROM SIX-PARENT DIALLEL CROSS, 1971

Pedigree	Generation	Rank (highest to lowest)	Grain Yield (gms)	
Ag/7654	F_2	1	420	a
Sut/Cmn	F_3	2	413	a
Sut/Ag	F_3	3	399	ab
Sut/Tmp 64	F_3	4	384	abc
Sut/Ag	F_2	5	381	abcd
Sut/7654	F_2	6	381	abcd
Sut/7654	F_3	7	379	abcde
Sut/Cmn	F_2	8	376	abcde
Sut/Tmp 64	F_2	9	376	abcde
Tmp 64/Cmn	F_2	10	365	bcdef
Ag/Cmn	F_2	11	363	bcdef
7654/Cmn	F_2	12	363	bcdef
Ag/Cmn	F_3	13	362	bcdef
Cmn	P	14	356	bcdefg
Ag	P	15	356	bcdefg
Sut	P	16	352	cdefgh
Sut/Sdy	F_2	17	350	cdefgh
7654/Cmn	F_3	18	349	cdefgh
Ag/7654	F_3	19	347	cdefgh
Tmp 64/7654	F_2	20	346	cdefgh
Tmp 64/Cmn	F_3	21	345	cdefgh
Tmp 64/Ag	F_2	22	343	cdefgh
Sut/Sdy	F_3	23	342	cdefgh
Tmp 64/7654	F_3	24	340	cdefgh
7654	P	25	334	defghi
Sdy/Cmn	F_2	26	332	efghi
7654/Sdy	F_3	27	324	fghi
Tmp 64/Ag	F_3	28	323	fghi
7654/Sdy	F_2	29	319	fghi
Sdy/Cmn	F_3	30	314	ghij
Tmp 64	P	31	311	ghij
Tmp 64/Sdy	F_2	32	310	ghij
Ag/Sdy	F_2	33	309	ghij
Ag/Sdy	F_3	34	308	hij
Tmp 64/Sdy	F_3	35	293	ij
Sdy	P	36	273	j

Note: Those means not followed by the same letter are significantly different at P = .05; means followed by the same letter are not significantly different at P = .05.

TABLE XXXV

MEAN SQUARES FROM ANALYSIS OF VARIANCE OF DATA FROM F_1 HYBRIDS FROM SEVEN-PARENT DIALLEL CROSS, 1969

Source of Variation	d.f.	Heading Date	Plant Height	Spike Number	Kernel Weight	Kernels/ Spike	Grain Yield
Replications	7	10.081**	224.450**	132.523**	0.255**	15.408**	146.972**
Hybrids	20	142.613**	1932.243**	184.505**	7.944**	233.399**	383.642**
Reps x Hybrids	140	2.452**	190.017**	58.531**	0.338**	12.651**	68.377**
Sampling Error	504	0.577	141.155	9.186	0.099	5.623	12.221

*Significant at 5% level.

**Significant at 1% level.

TABLE XXXVI

MEAN SQUARES FROM ANALYSIS OF VARIANCE OF DATA FROM F_2 HYBRIDS FROM SEVEN-PARENT DIALLEL CROSS, 1969

Source of Variation	d.f.	Heading Date	Plant Height	Spike Number	Kernel Number	Kernels/ Spike	Grain Yield
Replications	7	28.309**	148.696**	122.650**	0.575**	27.515**	86.174**
Hybrids	20	153.927**	986.141**	49.654**	6.153**	209.059**	66.091**
Reps x Hybrids	140	4.023**	54.746**	34.195**	0.651**	22.255**	34.422**
Sampling Error	504	2.937	25.885	9.797	0.150	8.557	12.989

*Significant at 5% level. **Significant at 1% level.

TABLE XXXVII

MEAN SQUARES FROM ANALYSIS OF VARIANCE OF DATA FROM F_2 HYBRIDS FROM SIX-PARENT DIALLEL CROSS, 1970 AND 1971

Source of Variation	d.f.	Year	Heading Date	Plant Height	Spike Number	Kernel Weight	Grain Yield
Replications	5	1970	6.491**	55.724**	71.591	0.230	33.267*
		1971	--	--	144.611**	0.243**	26.645*
Hybrids	14	1970	17.563**	13.187**	112.640*	0.314	27.902
		1971	--	--	186.272**	0.654**	70.139**
Error	70	1970	1.320	4.172	50.715	0.180	17.516
		1971	--	--	42.908	0.043	11.093

*Significant at 5% level. **Significant at 1% level.

TABLE XXXVIII

MEAN SQUARES FROM ANALYSIS OF VARIANCE OF DATA FROM F_3 HYBRIDS FROM SIX-PARENT DIALLEL CROSS, 1970 AND 1971

Source of Variation	d.f.	Year	Heading Date	Plant Height	Spike Number	Kernel Weight	Grain Yield
Replications	5	1970	7.004**	87.146**	49.658	0.104	26.961
		1971	--	--	190.718**	0.268**	52.104**
Hybrids	14	1970	18.878**	20.495**	104.225**	0.408**	52.142**
		1971	--	--	103.592*	0.572**	55.090**
Error	70	1970	1.247	4.728	32.994	0.140	21.489
		1971	--	--	50.018	0.057	10.591

*Significant at 5% level. **Significant at 1% level.

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