THE PERFORMANCE OF HYBRIDS AND VARIOUS HYBRID-PARENT MIXTURES OF FIVE SETS OF HARD RED WINTER WHEAT (*T. aestivum* L.) CROSSES

By

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CHAPTER I

INTRODUCTION

Since the discovery of cytoplasmic male sterility and genetic systems for fertility restoration in hexaploid wheat, many breeders have anticipated the commercial production of hybrids. The occurrence of commercial wheat hybrids seems inevitable since these mechanisms are available and are now being utilized. Hybrid wheat research has become a field of great interest and activity since the release of this information.

Many problem areas have developed concerning hybrid wheat which must be at least partially solved before wheat hybrids become economically feasible. Heterosis, particularly for yield, is one of the prerequisites for the successful utilization of hybrid wheat. Investigations on heterosis provided results ranging from little or no hybrid vigor in certain crosses to rather substantial amounts in others. Since restorer genes are not widely occurring in common wheat varieties, early identification of suitable restorer parents is of major importance. Many other problems exist and must be considered, but in general the major problems facing hybrid wheat are the economics of hybrid seed production and maximizing the profit potential of hybrid vigor. There is enormous genetic variability available in the species, and no doubt, outstanding hybrids can be developed if the right parental combinations are made.

There is great expense involved in producing enough hybrid seed for commercial planting, and this cost must be reduced before wheat hybrids become economically feasible. Because of the enormous cost of producing hybrid wheat, commercial seed companies have introduced the idea of blending male fertility-restoring (R-line) seeds with male sterile (A-line) seeds, and planting these as blends rather than in separate strips. This then would result in a product that would be part hybrid and part male parent (R-line) which would be used as the hybrid seed stock. A production system of this type would certainly reduce the cost of producing hybrid seed and yield performance of the hybrid-parent mixture produced in this manner might then be as good as the pure hybrid, assuming a competitive advantage of the hybrids over the non-hybrids.

The objectives of this study were: (a) to determine the level of heterosis in five combinations of hard red winter wheat; and (b) to examine the performance of hybrid-parent mixtures for five important agronomic characters as a possibility of utilizing heterosis in other than pure hybrid populations.

CHAPTER II

REVIEW OF LITERATURE

Heterosis

One of the most important factors determining the feasibility of commercial hybrid wheat is the nature and extent of heterosis that exists in the species. In the utilization of hybrid vigor for commercial crops, only that vigor in excess of the better parent is of significance. Briggle (3) made a comprehensive reivew of heterosis in wheat and cited instances of increased yields up to 84% above the highest yielding parent. Heterosis for other agronomic characters including components of yield, height, and maturity was also reported. He emphasized that caution should be exercised when evaluating reports of hybrid vigor, since virtually all heterosis studies involving wheat had been conducted on rather small populations in either the field or greenhouse. Data of this type may not be directly applicable to conventional nursery plots or conditions under which the hybrids would be grown.

Johnson, et al. (16) studied F_1 and F_2 populations of a cross involving two hard red winter wheat varieties, "Seu Seun 27" and "Blue Jacket". These varieties differed greatly with regard to several agronomic characters including plant height, spike length, yield of grain, maturity, and seed weight. High-parent heterosis for yield, kernel weight, and number of spikes was reported. Both F_1 and F_2 means for yield and number of spikes exceeded those of the best parent.

Many studies have demonstrated heterosis for grain yield in inter-varietal crosses, both under spaced and solid seeding. Of particular importance, however, is the choice of parents for the production of hybrids which demonstrates significant heterosis for important characters. Lee (17) working with crosses involving seven hard red winter wheat varieties, evaluated hybrids for several agronomic characters. None of the hybrids expressed significant high-parent heterosis for yield or any of the yield components, although 13 hybrids exceeded their respective high-parent for yield. The mean yield of the hybrids ranged from 72 to 146% of the high-parent values and the mean of all hybrids was 105% of the mean of all high-parents. McNeal, *et al*. (20) evaluated F_1 and F_2 generations of three spring wheat crosses for several agronomic and quality characteristics. The seeding rate was about one-half the normal planting rate for wheat. The F_1 and F_2 populations appeared to be intermediate between the parents for both agronomic and quality traits, and no significant high-parent heterosis was observed for any trait. Quality characteristics regressed toward those of the best parent. They pointed out that the parental lines involved in this study represented a rather narrow gene base, and emphasized the necessity of utilizing parents of wide genetic diversity in the development of wheat hybrids.

Gyawali, *et al*. (12) measured grain yield, kernel weight, and spike number in 21 inter-class F_1 hybrids. They reported yields ranging from 86 to 176% of the high-parent, with kernel weights ranging from 100 to 121% of the high-parent. Their results indicated that inter-class diversity was not necessary for the 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.

Brown, et al. (4) observed heterosis in a study of 16 F_1 wheat hybrids involving three soft winter varieties and four hard winter varieties. Seeds of the hybrids along with the seven parents, were grown in hill plots in a randomized complete block design. Hybrids ranged from 96 to 131% of the high-parent means, and none of the hybrids was significantly lower in yielding capacity than the high-parent. Along with the increase in yielding capacity, no significant reduction in percent protein was observed. Kernel protein percentage of the hybrids ranged from 92 to 105% of the high-parent means, indicating that hybrids may exhibit significant yield increases without a simultaneous decrease in percent protein. These results indicated that considerable heterosis for grain yield may be encountered with some F_1 wheat hybrids while others show little or no heterosis.

The performance of hybrids in spaced plantings, in hills, and in thinly planted nursery yield plots was investigated by Fonseca and Patterson (8), who studied several agronomic characters in F_1 and F_2 wheat populations and evaluated hill-plantings as a technique of determining heterosis. Both the F_1 and F_2 hybrids expressed significant high-parent heterosis for grain yield, kernel weight, and number of spikes. High-parent heterosis of the F_2 hybrids averaged 10% higher in hills than in nursery plantings in 17 of 21 cases. These workers concluded that the advantages of hybrids may tend to be overestimated in hill plantings.

Under near-normal field testing procedures, Livers and Heyne (19) noted that 18 hybrids averaged 20% over the mean value of seven parents for yield. They concluded that certain hard red winter wheat hybrids grown under near-solid seeding could express significant heterosis for yield.

Glover (11) studied heterosis of several agronomic traits in eight wheat hybrids. Three of the eight hybrids expressed significant high-parent heterosis of 16 to 18%, however, no hybrid significantly out-yielded the best check variety. Spike number was significantly lower than respective mid-parent values for all hybrids and seven of the eight hybrids were equal to their respective mid-parent values for kernels per spike. Only one hybrid had a lower kernel weight than the high check variety. It was concluded from this study that kernel weight was the most important factor contributing to yield and that kernels per spike was of more importance than number of spikes in the expression of heterotic yields.

For hybrid wheat to be successful, heterosis for grain yield must be sufficient to provide an economic return. Patterson and Bitzer (21) working with intercrosses involving several parental lines, reported yields in excess of the better parent. They obtained hybrids which yielded as much as 70% more than the best parent. They estimated that a 15 to 30% increase in yield would be necessary to pay for the extra cost of producing hybrid seed.

Varietal Mixtures

There is renewed interest in the possible use of varietal blends in a number of crop species. Practical advantages of mixtures of different varieties of the same species might include: (a) a cooperation between genotypes; (b) a stabilizing effect on yield; and (c) a reduction in disease (10).

Jensen (14) presented a rather comprehensive review on the importance of diversification in plant breeding. He pointed out that if a new method of developing a variety through the use of mixed populations is found, it should meet existing standards of uniformity; particularly height and maturity, resistance to diseases, and other characteristics essential for a basic desirable agronomic type. Unimportant, individual characteristics would not distract from the uniformity of the mixed populations because of the blending effect which would tend to mask them. He added that a multiline variety would possess a longer varietal life, i.e., tend to be more stable in important agronomic characters. This stability could be enhanced by changing the composition of the multiline with the development of new conditions which might tend to make it less stable.

Numerous examples have been presented in the literature that show mixtures of genotypes within a species produce higher seed yields than do the average of the cultivars that make up the composites. Probst (23) compared the yields of three soybean varieties and all possible blends, with some variation in the ratio of component parts. These varieties differed markedly in maturity and height, and to some extent in growth type and lodging susceptibility, and disease reaction. None of the blends was superior to the best yielding variety in any one year; however, over four years of testing, one blend averaged as high as the highest yielding variety comprising the blend. These data indicated that blending may be of importance in stabilizing yields from year to year and to produce near maximum yields each year. Patterson, et al. (22) working with six varieties of spring oats, studied standability of the varieties separately and as two-variety blends. They found the blends to be somewhat superior in standing ability, but not in yield.

In each case, the two varieties which made up the blends differed in maturity, thus when one variety was in the most susceptible stage for lodging it received some support from the second variety.

Allard (1) studied 10 lima bean populations representing three levels of genetic diversity, at four locations during a four year period to determine if productivity and stability of productivity were related to genetic diversity. He found that simple mechanical mixtures of two or three lines produced consistently less than the mean of the component pure lines grown singly. Genetically complex populations derived by bulk propagation from hybrids between the same parents yielded as much, or more than the superior pure line parent. The simple mechanical mixtures were more stable than the pure lines; however, there was little difference in stability among the different blends being composed of different numbers of pure lines. The bulk hybrid populations generally produced only slightly less yields than the pure lines in any one environment. The bulk hybrid populations studied were not composed of lines selected for high yields and compatibility. Blends of selected bulk hybirds may, therefore, have good yield stability and higher productivity than the best adapted variety. It was concluded that the blends were buffered against very low yields, but that the genetic and ecological forces which cause stability do not necessarily always endow mixtures with high average productive capacity.

Stringfield (28) planted 42 pairs of corn hybrids separately and as two-hybrid mixtures. Tests were conducted in northwestern Ohio in one season and in southwestern Ohio in two seasons, but no mixture was tested in more than one season or location. The mixtures performed about as expected based on the performance of their individual components. No measurable advantage in productiveness was noted in the hybrid blends to suggest any cooperation or facilitation between genotypes.

Information on the relative performance of lines when grown singly and in mixtures should be evaluated before selecting the varieties which are to be consolidated into multilines. The success of a mixture depends on its yield in relation to the highest yielding component line. Bussell (6) studied the average annual yields of oats and barley grown singly and in combination. The field blend, including the weighted average, produced as much or more (ranging from 100 to 109%) than the average of the single component yields. Zavitz (29) evaluated the yield of barley, oats, spring wheat, and peas grown separately and in various combinations. In 10 of the 11 comparisons the average yield of the mixtures exceeded that of the varieties grown separately. The relative efficiency of the different combinations ranged from 93% for the peas and wheat to 127% for the oats, barley, and wheat mixture. Jensen (14) working with six varieties of oats in pure stands and in various combinations, found that in all cases the yield of the field blend exceeded that of the average of the single variety yields.

Jensen (15) examined the general yield relationship of composites to the mean yield performance of component lines, and also specific multiline relationship to the mean yield performance of component lines and commercially available single-line varieties. In general, the unselected composites were slightly (3.2%) but not significantly higher yielding than the mean of their components when grown separately. Composites held an advantage in six out of eight years. In the specific case, a multiline of 5 components, selected on the basis of anticipated favorable intrapopulation response (genotype interactions), was tested. The bases for selection were not discussed. This multiline of deliberate design, was significantly higher yielding (7.3%) than the mean yield of its component lines and slightly higher than the best two pure lines grown separately. Jensen concluded that greater yield superiority may be realized if selected lines are used in constructing the multiline varieties.

Stability of yield is generally a desirable characteristic of a variety when stability refers to consistent high performance in all environments. Rasmusson (24) working with simple mechanical mixtures and complex barley mixtures (bulk hybrids), investigated yield and stability of yield. The relative yields of simple mixtures exceeded the mean yield of the component parts in almost every case. Complex mixtures as a group were significantly lower than their respective parents. One complex mixture significantly outyielded its parental varieties by 7%. Neither simple nor complex mixtures produced more than the highest yielding variety; however, there was a tendency for greater stability in the complex mixtures. There was no indication of greater stability in the simple mixtures than in the homogeneous varieties.

In general, other investigators have found enhanced stability in both simple and complex mixtures when compared to homogeneous varieties. Funk and Anderson (10) studied the effects of blending several corn hybrids. All mixtures yielded about the same as the average of their components when grown separately. There were considerable differences in the competitive ability of the hybrids involved in the composites. The actual contribution of the individual components of a mixture differed widely from what was expected based on their performance in pure stands. Blends of the corn hybrids resulted in greater yield stability as compared to component hybrids. Frey and Maldonado (9) tested six oat cultivars (three early, two midseason, and one late) in 57 different mixtures for yield at two sowing dates (early and late) for three years. The advantage of the heterogeneous populations increased as the environment became more stressed. Only one mixture yielded significantly better than expected for the early planting and eight were significantly better for the late planting. There was no correlation between the number of cultivars which went into the mixtures and the grain yield of the mixtures. Several mixtures yielded more than the best cultivar when averaged across the two sowing dates. This work indicated that the mixtures gave more stable production than did the individual homogeneous cultivars.

Relatively few instances of mixtures resulting in statistically significant higher yields than their individual components have been reported. Ross (26) conducted a study to test mixtures of grain sorghum single-cross hybrids. The study involved mixtures of five single-cross hybrids which were grown in 1:1 blends for five years. The hybrid blends yielded nearly as expected based on the mean performance of their individual components. No blend exceeded the yield of the best hybrid. The hybrids were of quite varying genotypes and significant differences within blends and within hybrids existed each year. It was concluded that for this study there seems to be no particular advantages or disadvantages for grain sorghum blends. Clay and Allard (7) compared 23 mixtures of barley varieties with their components for yielding ability and yield stability at five locations over two years. The mixtures had a small advantage in yield over the average of their components but were inferior in stability of yield. The number and diversity of components in the mixtures appeared unrelated to yield. It was concluded that simple varietal mixtures have limited commercial possibilities and that special breeding programs may be necessary if favorable inter-genotypic interactions are to be utilized.

Burton (5) mixed F_1 hybrid pearl millet seed with inbred parental seed in proportions of 90, 80, 50, and 20% F_1 hybrid to 10, 20, 50, and 80% inbred parent, respectively. The mixtures were planted at a rate comparable to that obtained with common farm practices. Three forage clippings were taken and compared with those of the 100% hybrid and 100% inbred parent mixtures. Yield data collected for six years showed that hybrid-parent mixtures yielded more than expected based on their component parts. The six year average yields of the different mixtures gave an increase from 3.5 to 8.5% compared to what was expected based on their component parts. The average yields of the 100, 90, 80, and 50% hybrid-parent mixtures did not differ significantly. This indicated that over a period of years most any mixture within this range might be expected to yield as much as the 100% hybrid.

In one year of the study, the forage yields approached the expected yields more closely than in the other years of the test. This was credited to a prolonged drought period which followed the date of planting. In the other five years, increased yields of the mixtures were attributed to early competition, which tended to eliminate the less vigorous inbred parent seedlings, and thereafter the plots planted to mixtures would behave similar to the pure hybrid plots.

The interpretation of Burton's findings stemmed from the results of another experiment, being conducted at the same time by Burton (5), where he designed a test to check the effects of seeding rate upon the yield performance of hybrid-parent seed mixtures. Subsequent mixtures containing 100, 80, 50, and 0.0% hybrid seed were prepared for three different millet hybrids. Mixtures were planted at rates equivalent to 2.2, 4.5, and 17.9 kg/ha in rows spaced 76-cm apart. When approximately 7.6 cm high, the seedlings in 50.8 cm of row in each plot were counted. The proportion of parent plants tended to be reduced as the seeding rate increased. Hybrid seed consistently gave more plants per cm of row than the inbred parent seed. This was credited to the greater seedling vigor of the hybrids and was used as the basis for explaining early hybrid-parent competition.

The promising results obtained from the use of homogeneous blends may be directly applicable to a system for production of commercial wheat hybrids. Roberts (25) has discussed the possibility of blending 10 to 20% of the male fertility-restoring (R-line) seeds with 90 to 80% of male sterile (A-line) seeds, and planting these as blends rather than in separate strips. This then would result in a product that would be part hybrid and part male parent in a ratio depending on the initial ratio of the mixture as well as other factors. Increased seed set should be realized because pollen from the R-lines would have to travel less distance than would be the case when males and females are planted in separate drill strips. The yield performance of the hybrid-parent mixtures produced in this manner might then be as good as the pure hybrid, assuming a competitive advantage of the hybrid plants over the non-hybrids. Increased seeding rates of the hybrid-parent mixture, as suggested by Burton (5), could be utilized to enhance early elimination of the less productive non-hybrids. A production system of this type would obviously reduce the cost of producing hybrid seed.

CHAPTER III

METHODS AND MATERIALS

Hybrids and Parental Lines

The material used in this study consisted of five varieties of hard red winter wheat, five pollen fertility restorer lines, and the five F_1 hybrids developed from crosses of the five cytoplasmic male sterile lines of the aforementioned varieties with the different restorer lines. All male sterile lines had the *T. timopheevi* cytoplasmic male sterile system. The genetic system for fertility restoration of the restorer lines was also derived from *T. timopheevi*.

The varieties used in this study were chosen to represent a range in genetic diversity for major agronomic characteristics. The availability of F_1 hybrid seed was also a factor in the selection of lines to be tested. The F_1 hybrids evaluated in this study were: (a) A-Agent/R93-25; (b) A-Kaw 61/R93-8; (c) A-Scout/R92-25; (d) A-Shawnee/R93-18; and (e) A-Sturdy/R92-23.

The restorer lines were Oklahoma selections; R93-25, R93-8, R92-25, R93-18, and R92-23, and traced to single plant selections from the Nebraska 54237 restorer population which was obtained from Dr. J. C. Craddock in July of 1963. The pedigree of the 54237 restorer population is *T. timopheevi* x (Hussar-Hard Federation)^2 x (Comet-Hussar-Hard Federation) x Nebred. The population consisted of two lots of seed, designated as lot 1 and lot 2. Reports from Nebraska indicated that lot 1 had two major genes for restoration while lot 2 had a single major gene with possible minor genes associated. The F_2 generation of these two lots were grown at Stillwater in 1964 with lot 1 as plot 5892 and lot 2 as plot 5893. Individual F_3 plant selections were made from each lot and the resulting populations from these selections carried the selection numbers of Stw 645892 and Stw 645893 plus the plant selection number. In all, some 70 F_3 plant selections were made and five of these selections were used in this study. The choice of restorer lines was based on degree of fertility restoration and agronomic characteristics as determined in previous tests conducted at the Oklahoma Agricultural Experiment Station (11).

The male sterile lines used were: 'Agent'; 'Kaw 61'; 'Scout'; 'Shawnee'; and 'Sturdy'. Agent was developed at the Oklahoma Agricultural Experiment Station and released in 1967. It is described by Smith, et al. (27) as being resistant to all known races of leaf rust in Oklahoma, carring acceptable resistance to all common races of stem rust, mid-season in maturity, and mid-tall with white glumes. Kaw 61 was released by the Kansas Agricultural Experiment Station in 1961 to replace 'Kaw'. It is medium in maturity with outstanding test weight and baking qualities (18). Scout was released by the Nebraska Agricultural Experiment Station in 1963. It has good milling and baking characteristics and carries resistance to race 56 stem rust. It is very winter-hardy and is medium-early in maturity (18). Shawnee is a hard red winter wheat selected in Kansas from the cultivar 'Ottawa' and released in the fall of 1967. Shawnee has the same characteristics as Ottawa, except that it may be slightly later and taller. It has a longer mixing time and distinctly better mixing tolerance than Ottawa (13). Sturdy was developed by the Texas Agricultural Experiment Station and the U.S.D.A. and released in 1966. It is a true semi-dwarf with strong straw and shows strong resistance to lodging. It has medium maturity and is 10-13 cm shorter than 'Triumph', but has a lower test weight. It has good baking quality characteristics (2).

The Field Layout

The field layout was a randomized complete block design. Each block contained 30 plots. Each plot was 3 m long and consisted of 2 rows. The study consisted of five hybrid-parent mixtures for each of five variety sets. Also, included were the five B-line parents which served as variety checks (Table I). Each entry in the study was replicated six times. The various percentages of grain in each treatment were obtained by weighing out the proper amount of the F_1 hybrid seed and mechanically mixing it with the proper amount of seed from the restorer line. The percentage of the various components was based on seed number and not seed weight.

The various mixtures, along with the check varieties, were planted with a tractor-mounted cone planter on October 4, 1969, at the rate of 200 seeds per 3 m of row. This is comparable to the standard seeding rate for wheat in this area of about 67.26 kg/ha (1 bu/A). The rows were 30 cm apart.

The field which was located on the Agronomy Research Station at Stillwater, had received approximately 35 kg/ha each of P_2O_5 and NH_4NO_3. A supplemental application of 45 kg/ha of actual N in the form of NH_4NO_3 was applied in March of 1970.

TABLE I

COMPOSITION OF HYBRID-PARENT MIXTURES

Variety Set[1]		
Mixtures[2]		
% F_1 Hybrid	% R-Line	% B-Line
00.0	100.0	00.0
50.0	50.0	00.0
75.0	25.0	00.0
87.5	12.5	00.0
100.0	00.0	00.0
00.0	00.0	100.0

[1]In these and in subsequent analyses the different variety sets refer to above mixtures involving the following: Scout Set -- A-Scout/R92-25+R92-25; Agent Set -- A-Agent/R93-25+R93-25; Sturdy Set -- A-Sturdy/R92-23+R92-23; Shawnee Set -- A-Shawnee/R93-18+R93-18; Kaw 61 Set -- A-Kaw 61/R93-8+R93-8.

[2]Mechanical mixtures based on number of seed.

Characters Evaluated

All observations were recorded on each plot. The characters evaluated were: (a) heading date; (b) grain yield; (c) kernel weight; (d) kernels/spike; and (e) tiller number.

Heading Date

Heading date was used as a measure of the relative maturity of the parents and hybrid-parent mixtures. Heading date was recorded as the number of days from January 1 to the time when about three-fourths of the heads were emerged from the boot.

Grain Yield

Yield determinations consisted of the weight of threshed grain from two 2.4 m rows which were prepared from the two 3 m rows by cutting 0.6 m from each end of the two rows. Yields were expressed in grams per plot.

Kernel Weight

Kernel weight was determined by weighing 200 random kernels from each plot. Weights were expressed as grams/1000 kernels.

Kernels/Spike

The average number of kernels/spike was calculated by the following formula:

$$\frac{\dfrac{\text{grain yield in grams}}{\text{average weight/kernel in milligrams}}}{\text{total number of spikes per 900 cm}^2}\ .$$

Tiller Number

This character was determined by counting the number of tillers in 30 cm of row for each of the two rows in each plot. Tiller number was expressed as the number of seed-bearing tillers per 900 cm^2. This was obtained by averaging the two counts of each plot.

Statistical Analysis

Heterosis was measured for all F_1 populations in relation to both the mid-parent and the high-parent values. The test of Least Significant Difference (LSD) was used for each contrast. The variance of each contrast is defined as

$$\text{Sd for } F_1 \text{ vs Mid-Parent} = \sqrt{\frac{3 \text{ EMS}}{2r}}$$

$$\text{Sd for } F_1 \text{ vs High-Parent} = \sqrt{\frac{2 \text{ EMS}}{r}}$$

where EMS is the experimental error mean square and r represents the number of observations composing the treatment mean. The LSD values were calculated as follows:

$$\text{LSD} = S_d t_{(\alpha,\ t-1)} \quad .$$

Statistical analysis was also performed on heading date, yield, and the components of yield of each hybrid-parent mixture. Each character was analyzed by the analysis of variance where the percent hybrid was regressed on its performance for each character. The data were analyzed in this manner because of the increment increase in percent hybrid of the various mixtures.

CHAPTER IV

RESULTS AND DISCUSSION

Heterosis

Growing conditions throughout the extent of this study were generally favorable; however, rainfall was slightly below normal. Average grain yield of all F_1s and their parents was 359.3 grams per plot which is equivalent to 35.9 bushels per acre. There were no problems with disease or insects, and no winterkilling or lodging occurred.

Mean squares from the analysis of variance of the five agronomic characters on 5 F_1 hybrids, their 10 parents, and the 15 hybrid-parent mixtures are presented in Table II. Mean squares for kernel weight in all five sets were highly significant. Two sets out of five showed highly significant difference for yield and one was significant at the .05 level of probability. Only one set showed significantly different effects on kernels/spike. Tiller number produced three sets that were highly significant and one which was significant at the .05 level. Mean squares for heading date were highly significant in four sets. Parent and hybrid means, and hybrid deviations for the five traits are presented in Appendix Tables V-IX.

Heterosis in relation to both mid-parent and high-parent values was examined for all characters analyzed. Means of all F_1s for the five characters measured were expressed as the percentage of their respective high-parent and mid-parent means (Table III). Two out of the

TABLE II

MEAN SQUARES FROM THE ANALYSIS OF VARIANCE FOR F_1 HYBRIDS, PARENTS, AND HYBRID-PARENT MIXTURES

Source of Variation	df	Heading Date	Yield	Kernel Weight	Kernels/ Spike	Tiller Number
Mixtures in Scout Set	5	19.644**	11391.583**	12.857**	1.270	171.867**
Mixtures in Agent Set	5	.844	13525.133**	15.031**	3.685	187.428**
Mixtures in Sturdy Set	5	15.428**	1908.717	15.936**	2.231	25.028
Mixtures in Shawnee Set	5	2.178**	1306.361	15.599**	3.855	218.694**
Mixtures in Kaw 61 Set	5	6.183**	4701.828*	12.798**	8.859*	144.533*
Error	145	.688	1766.714	1.410	3.485	45.566

*Significant at the .05 level of probability.

**Significant at the .01 level of probability.

TABLE III

MEAN PERFORMANCE OF HYBRIDS EXPRESSED AS PERCENT OF MID-PARENT AND HIGH-PARENT VALUES

F_1 Hybrid		Heading Date[1] %MP	Heading Date[1] %HP	Yield %MP	Yield %HP	Kernel Weight %MP	Kernel Weight %HP	Kernels/Spike %MP	Kernels/Spike %HP	Tiller Number %MP	Tiller Number %HP
A-Scout/R92-25		101*	99**	113*	96	107*	100	98	97	109	98
A-Agent/R93-25		101*	101	124**	120**	113**	112**	100	93	108	97
A-Sturdy/R92-23		102**	100	106	102	109**	101	96	94	100	96
A-Shawnee/R92-18		100	99*	95	90	115**	109**	86*	84**	95	84**
A-Kaw 61/R93-8		98**	98**	109	98	112**	105	97	88	101	95
5% LSD	MP	.83 days		42 g		1.2 mg		1.8 kernels		6.7 tillers	
	HP	.95 days		48 g		1.4 mg		2.1 kernels		7.7 tillers	
1% LSD	MP	1.10 days		55 g		1.6 mg		2.0 kernels		8.8 tillers	
	HP	1.25 days		63 g		1.8 mg		2.3 kernels		10.2 tillers	

[1]High-parent was considered as the earlier maturing of the two parents.

*Significant at the .05 level of probability.

**Significant at the .01 level of Probability.

five hybrids were earlier than the earlier parent and one was later than the late parent. The high-parent in each case was considered as the earlier maturing of the two parents. Three out of the five hybrids in this study, A-Scout/R92-25, A-Shawnee/R92-18, and A-Kaw 61/R93-8, were significantly later in maturity than their respective high-parent, with A-Kaw 61/R93-8 being significantly later than its mid-parent for heading date. Days to heading of the various hybrids are shown in Appendix Table V.

Two of the five hybrids, A-Scout/R92-25 and A-Agent/R93-25, exhibited significant mid-parent heterosis for yield with A-Agent/R93-25 yielding significantly more than its high-parent. None of the hybrids was significantly lower in grain yield than its respective mid-parent or high-parent values. Yield increases above the higher yielding parent ranged from 2.4% for A-Sturdy/R92-23 to 19.9% for A-Agent/R93-25. These two hybrids also produced yields in excess of the highest yielding check variety (Appendix Table VI). Both of these hybrids expressed significant mid-parent heterosis for kernel weight and A-Agent/R93-25 was significantly better than its high-parent for this trait. The range for grain yield of the five hybrids was 90 to 120% of the high-parent means and 95 to 124% of the mid-parent means. The mean for all F_1s was 101% of the high-parent mean and 109% of the mid-parent mean.

The most striking heterotic effect observed in this study was for kernel weight. All five hybrids exhibited significant mid-parent heterosis for this character and two, A-Agent/R93-25 and A-Shawnee/R92-18, expressed significant high-parent heterosis. The heaviest kernel weight was observed in A-Agent/R93-25 (Appendix Table VII) which also had the highest yield. The average for all hybrids for this trait was 105 to

111% of the high-parent and mid-parent values, respectively. No hybrid was significantly lower than its high-parent for this character. These results are in agreement with other workers (11,16,17), who also observed that kernel weight was of major importance in the expression of heterosis for grain yield.

In this study, kernels/spike and tiller number appeared to be of less importance than other factors in contributing to grain yield. None of the hybrids exceeded its mid-parent value for kernels/spike while one, A-Shawnee/R92-18, was significantly lower than its mid-parent for this character. The mean for all hybrids was 91% of the high-parent value and 95% of the mid-parent value for kernel/spike. Four of the five hybrids exceeded their mid-parent values for tiller number but none was significantly higher. All hybrids produced less tillers than their respective high-parent and one, A-Shawnee/R92-18, was significantly less. This hybrid also produced the lowest number of kernels/spike. Together, these two characters probably explain why this hybrid was the lowest yielding of all entries involved in this study (Appendix Table X). Parent and F_1 means and hybrid mid-parent and high-parent deviations for kernels/spike and number of tillers are shown in Appendix Tables VIII and IX, respectively.

Hybrid-Parent Mixtures

Average grain yields for all entries, including the pure line varieties were 368.27 grams per plot which is equivalent to 36.8 bushels per acre. Grain yields ranged from 280 grams per plot for A-Shawnee/R92-18 F_1 to 470 grams per plot where there was a blend in the ratio of 87.5: 12.5 of A-Agent/R93-25 to R93-25.

Mean squares from the analysis of variance for all mixes and parents are shown in Table IV. Mean squares for three of the five sets showed a highly significant linear response for grain yield as the percent hybrid increased. One mean square for kernel weight indicated a highly significant linear response for mixtures involving the hybrid A-Kaw 61/R93-8 and three indicated a curvilinear response. Mixtures involving A-Shawnee/R93-18 indicated a quartic response in kernel weight as the percent hybrid increased. Mean squares for the other two hybrids showing a curvilinear response, A-Scout/R92-25 and A-Agent/R93-25, exhibited a significant quadratic response in kernel weight as the percent hybrid increased. More mixtures were significant for kernel weight than for any other component of yield. Mixtures which showed a significant difference for grain yield, also showed significant difference for kernel weight. Again this indicates that kernel weight is of major importance in the expression of grain yield.

The mean square for mixtures in only one set, the one involving A-Shawnee/R93-18, indicated a significant linear response in kernels/spike, and this set of mixtures gave no significant response in grain yield as the percent hybrid increased. The mean square for tiller number was significant in only one set of mixtures (A-Scout/R92-25) and indicated a highly significant linear response in tiller number as the percent hybrid increased. Four of the five sets of mixtures exhibited significant mean squares for heading date. The sets involving hybrids A-Scout/R92-25 and A-Sturdy/R92-23, indicated a significant quadratic response to heading date and the sets involving hybrids A-Shawnee/R93-18 and A-Kaw 61/R93-8, indicated a significant linear response.

The five agronomic characters observed were regressed on the

TABLE IV

MEAN SQUARES FROM THE ANALYSIS OF VARIANCE FOR PARENTS AND HYBRID-PARENT MIXTURES

Source of Variation	df	Yield	Kernel Weight	Kernels/ Spike	Tiller Number	Heading Date
Total	179					
Replication	5	2564.3	1.51	5.50	106.7*	11.63**
Sets	4	82346.9**	128.03	45.09**	318.5**	204.81**
Entries in Scout Set	5					
P2 vs Mixtures[1]	1	10442.4**	.35	.32	180.0*	41.08**
Mixture	4					
Linear	1	45264.9**	41.66**	.44	617.7**	54.14**
Quadratic	1	1015.4	22.24**	3.69	6.8	2.73*
Cubic	1	146.3	.01	1.43	19.4	.09
Quartic	1	88.6	.00	.43	35.5	.14
Entries in Agent Set	5					
P2 vs Mixtures	1	32805.0**	3.53	6.41	740.1**	.09
Mixture	4					
Linear	1	20487.5**	45.93**	7.38	18.7	1.20
Quadratic	1	365.5	6.01**	4.01	161.7	.44
Cubic	1	2649.1	.87	.20	16.1	1.98
Quartic	1	1318.3	1.15	.14	.3	.50
Entries in Sturdy Set	5					
P2 vs Mixtures	1	1786.0	71.25**	5.39	73.4	4.79**
Mixture	4					
Linear	1	534.0	.17	2.55	18.1	67.20**
Quadratic	1	278.7	3.27	.05	2.1	5.19**
Cubic	1	5930.1	3.44	2.73	2.8	.06
Quartic	1	1014.7	1.53	.40	28.4	.00
Entries in Shawnee Set	5					
P2 vs Mixtures	1	902.3	52.27**	.96	740.1**	6.42**
Mixture	4					
Linear	1	244.0	12.37**	15.81*	153.5	3.26*
Quadratic	1	4762.2	3.12	.08	80.5	.00
Cubic	1	622.3	.28	2.11	10.0	1.17
Quartic	1	.8	9.74**	.30	109.1	.02
Entries in Kaw 61 Set	5					
P2 vs Mixtures	1	3166.8	1.01	38.66**	404.9**	18.04**
Mixture	4					
Linear	1	15876.2**	59.50**	2.74	33.7	9.20**
Quadratic	1	3249.2	.76	.17	101.6	.19
Cubic	1	171.7	.02	.81	5.7	.29
Quartic	1	1045.1	3.59	1.89	26.5	.31
Error	145	1766.7	1.41	3.48	45.5	.68

[1]P_2 refers to the respective B-line parent.

*Significant at the .05 level of probability.

**Significant at the .01 level of probability.

various mixtures of each set, which showed a significant ordered response to the increase in percent hybrid (Figures 1-13). Figures 1, 2, and 3 show the linear regression line of grain yield on mixtures of the three sets involving the hybrids A-Scout/R92-25, A-Agent/R93-25, and A-Kaw 61/R93-8, respectively. A-Scout/R92-25 (Figure 1) has a regression coefficient of 1.1 for grain yield, i.e., as the amount of hybrid increases by one unit (percent) the grain yield increases 1.1 grams per plot. Figures 2 and 3 show the regression lines for the mixtures involving A-Agent/R93-25 and A-Kaw 61/R93-8, respectively, and have respective regression coefficients of .902 and .651 grams per plot. The regression of percent hybrid on the grain yields of these three hybrids indicates that as the percent hybrid increases, grain yield increases linearly. Therefore, production of a part hybrid, part male parent product would not be expected to yield as much as the 100 percent hybrid.

Two of the five sets of mixtures gave no significant ordered response in grain yield to the unit increase in percent hybrid (Appendix Figures 14 and 15). This seems to indicate that the production of part hybrid products, for economic reasons, involving one of these two hybrids, A-Sturdy/R92-23 and A-Shawnee/R93-18, would be feasible; for they would be expected to produce about as much as the pure hybrid population. Mean grain yields of the F_1 hybrids, parents, and the various mixtures are presented in Appendix Table X.

The mixtures involving A-Kaw 61/R93-8 gave a highly significant linear response to the increase in percent hybrid for kernel weight, with a regression coefficient of .04 grams per 1000 kernels for each

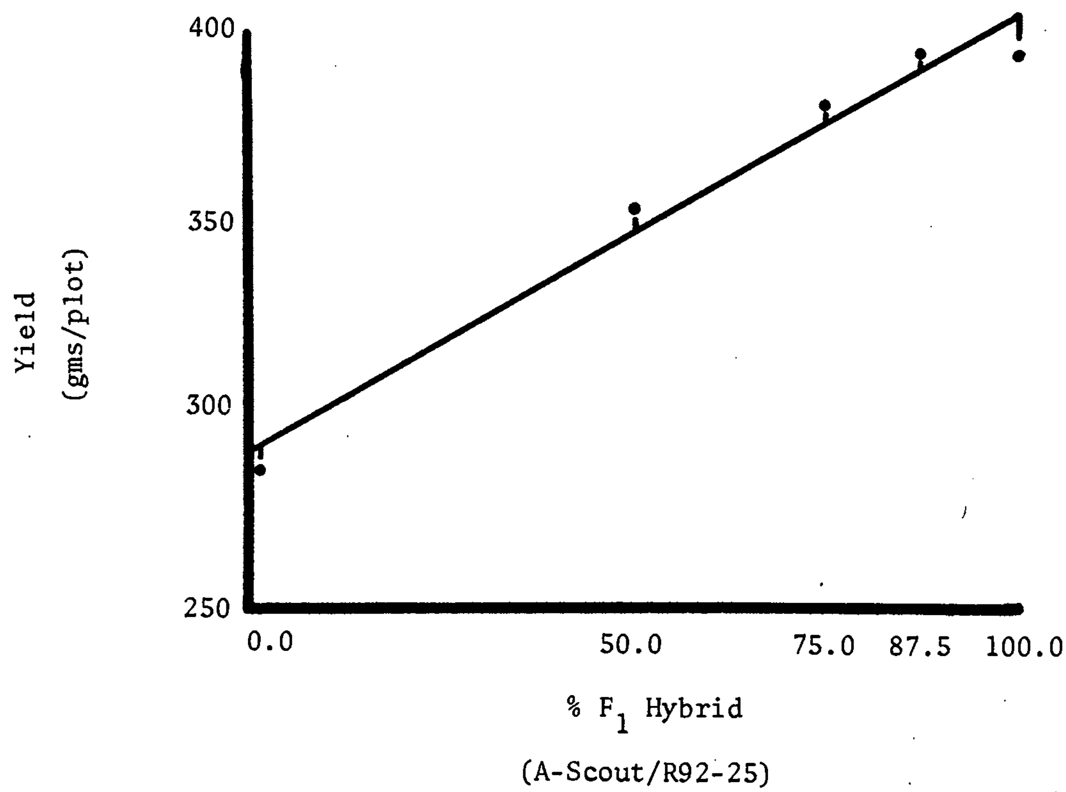

Figure 1. Regression Curve of Yield on Percent Hybrid in the Scout Set

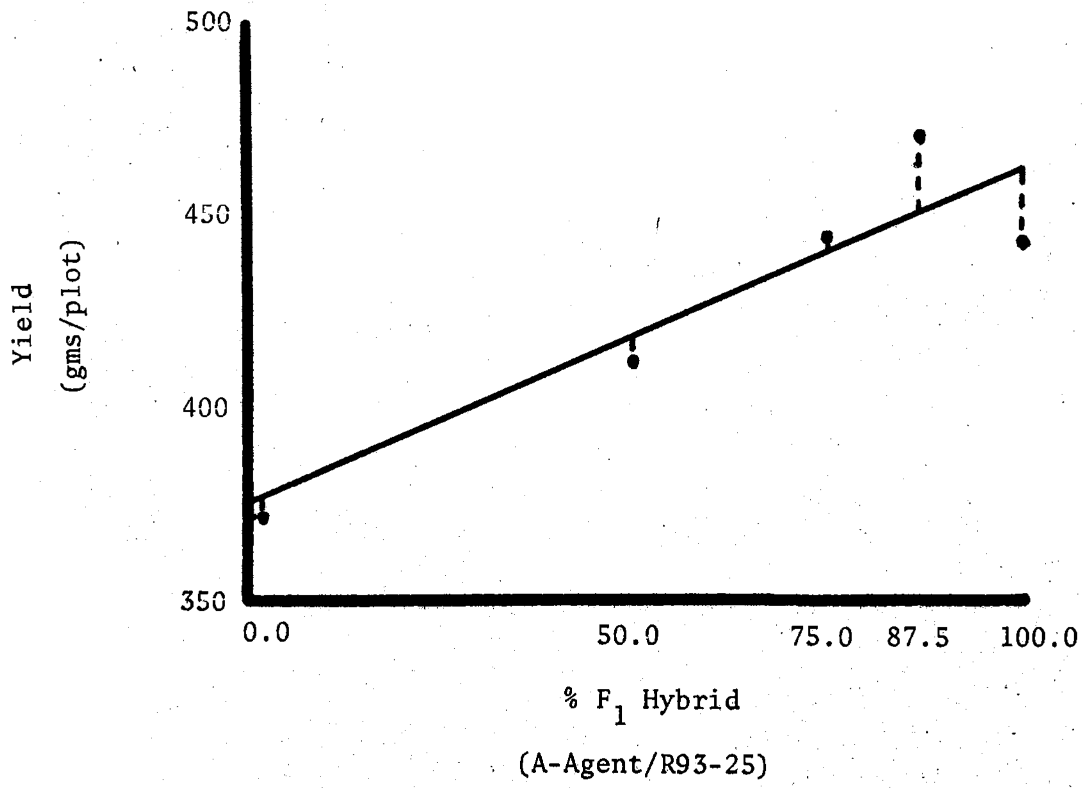

Figure 2. Regression Curve of Yield on Percent Hybrid in the Agent Set

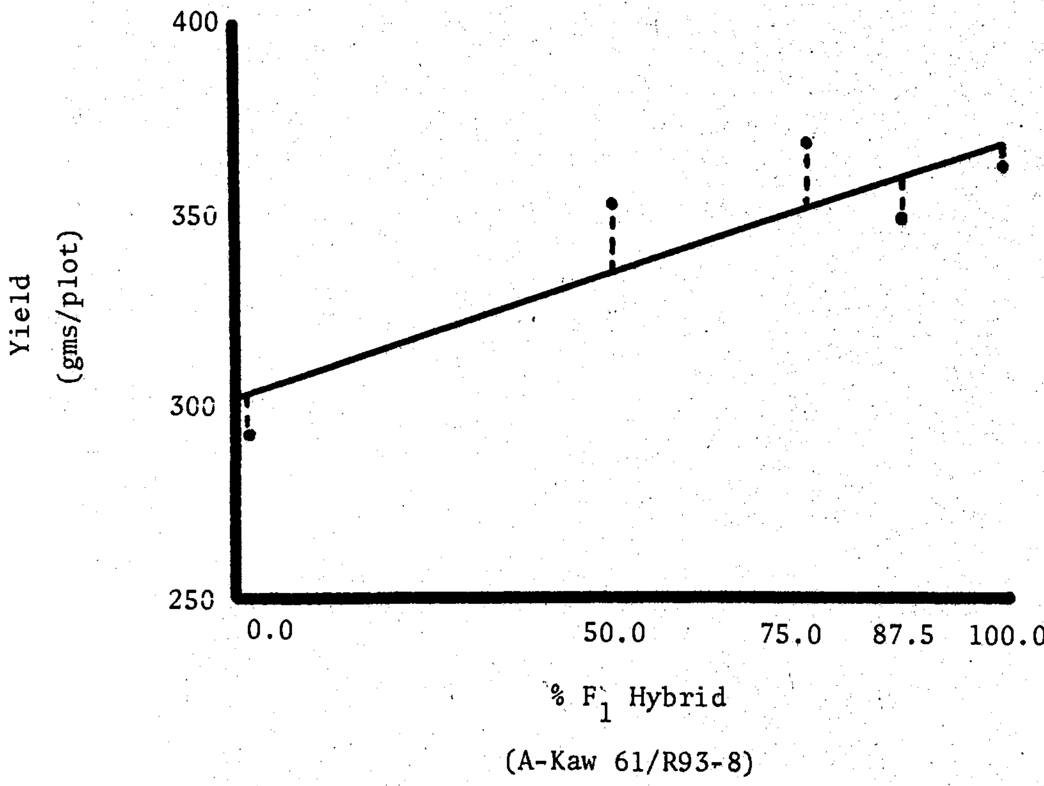

Figure 3. Regression Curve of Yield on Percent Hybrid in the Kaw 61 Set

unit increase in the percent hybrid (Figure 4). Mixtures involving A-Scout/R92-25 and A-Agent/R93-25 gave curvilinear responses. Kernel weight, for both sets of mixtures, increased in a quadratic fashion until a maximum was reached at about 75% hybrid (Figures 5 and 6). This indicates that an optimum ratio of hybrid and R-line parent exists, at least for these two hybrids, that will allow maximum expression of kernel weight.

The analysis of variance (Table IV) indicated that the kernel weight for the mixtures involving A-Shawnee/R93-18 responded in a quartic fashion with respect to the increase in percent hybrid. Kernel weight increased as the percent hybrid increased, reaching a maximum at 75% hybrid. There was a sharp drop in kernel weight as the percent hybrid increased from 75% to 87.5% and a sharp increase as the percent hybrid was increased to 100% (Figure 7). The unexplained drop in kernel weight for the 87.5% hybrid mixture occurred in each of the six reps. Therefore, this drop might have been due to error in seed preparation where the mixture actually consisted of 87.5% R-line and 12.5% hybrid instead of the intended 12.5% R-line and 87.5% hybrid. If this were the case, the data for this mixture would more closely fit the data obtained for the other mixtures of this set. Kernel weight for A-Sturdy/R92-23 indicated no significant ordered response as the percent hybrid was increased (Appendix Figure 16). Only one hybrid, A-Scout/R92-25, produced a significant ordered response in the number of tillers as the percent hybrid increased. This was a highly significant linear response with a regression coefficient of .128 tillers per 900 cm^2 (Figure 8).

The only significant negative response occurring for yield or components of yield, was for kernels/spike with the mixtures involving

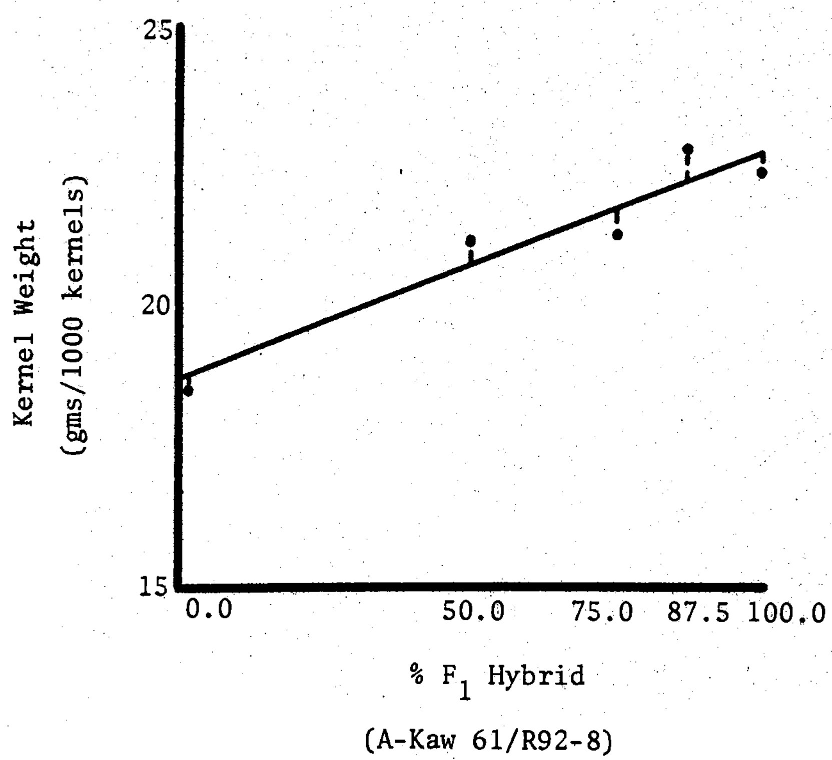

Figure 4. Regression Curve of Kernel Weight on Percent Hybrid in the Kaw 61 Set

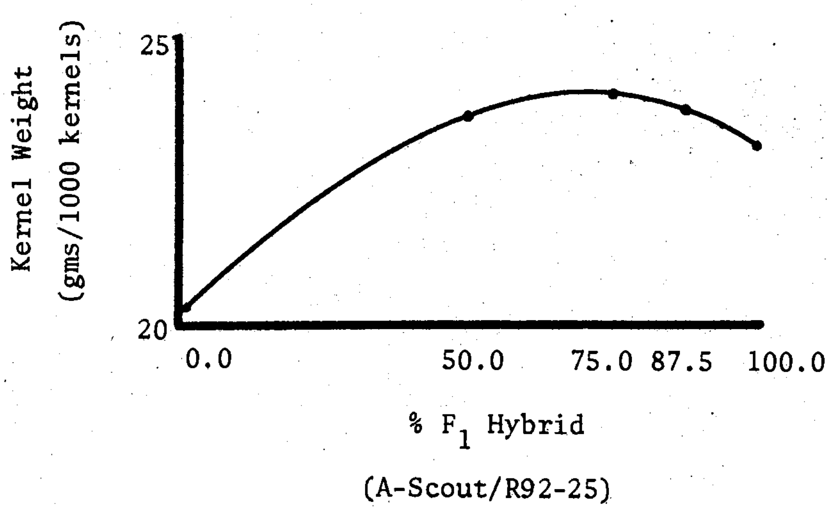

Figure 5. Regression Curve of Kernel Weight on Percent Hybrid in the Scout Set

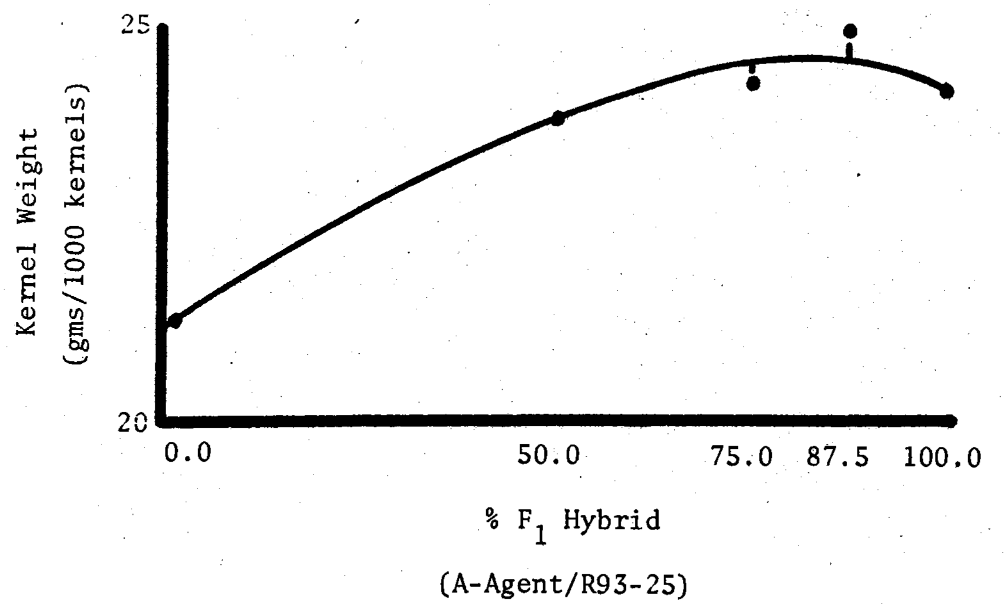

Figure 6. Regression Curve of Kernel Weight on Percent Hybrid in the Agent Set

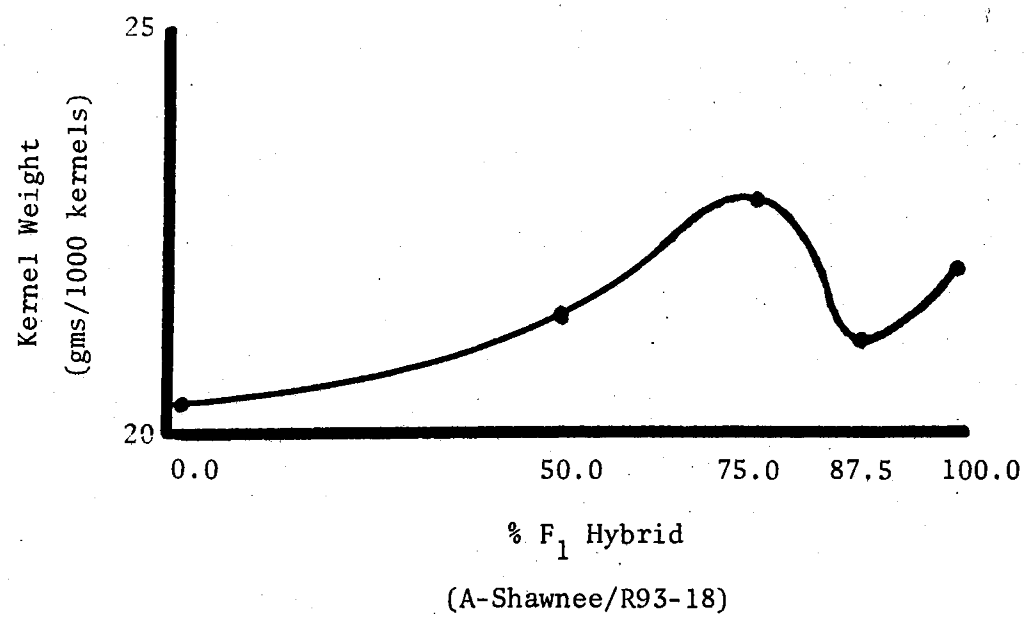

Figure 7. Regression Curve of Kernel Weight on Percent Hybrid in the Shawnee Set

A-Shawnee/R93-18. This was a significant negative linear response with a regression coefficient of -.025, i.e., as the percent hybrid increased by one unit the number of kernels per spike decreased by .025 (Figure 9). None of the other sets of mixtures gave significant ordered responses in the number of kernels/spike as the percent hybrid increased.

Four of the five sets of mixtures produced significant ordered responses for heading date in relation to the unit increase in percent hybrid. Two of the responses were linear (Figures 10 and 11), and two were curvilinear (Figures 12 and 13). A-Kaw 61/R92-8, Figure 10, showed a highly significant linear response with a regression coefficient of .016, and the linear response of A-Shawnee/R92-18, Figure 11, gave a negative regression coefficient of -.009. The mixtures involving A-Kaw 61/R92-8+R92-8 matured .016 days later with each unit increase in percent hybrid and the mixtures involving A-Shawnee/R93-18+R93-18 matured .009 days earlier with each unit increase in percent hybrid. The days required to reach maturity for mixtures involving A-Sturdy/R92-23 and A-Scout/R92-25 increased in quadratic fashions with maxima reached at about 75 and 85% hybrid for the two mixtures, respectively (Figures 12 and 13). Days to heading for A-Agent/R93-25 indicated no significant ordered response as the parent hybrid was increased (Appendix Figure 17).

In this study, kernel weights more closely paralleled yield fluctuations than the other two components of yield. The yield and components of yield of the different sets of mixtures, expressed as percent of the R-line, were plotted against the increase in percent hybrid and are presented in Appendix Figures 18-20.

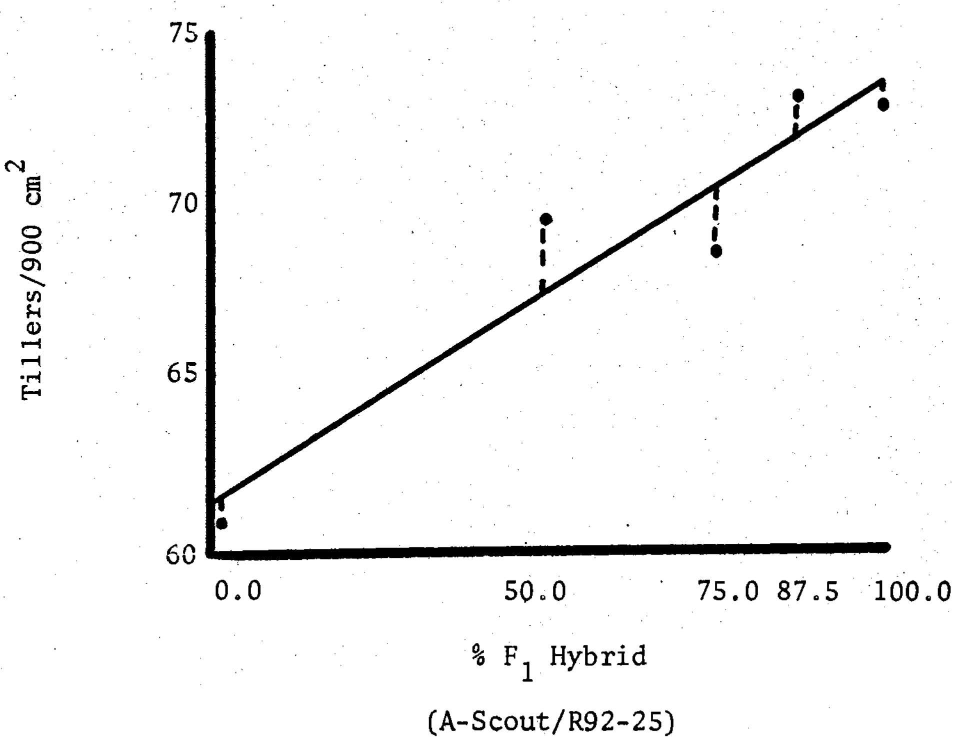

Figure 8. Regression Curve of Tiller Number on Percent Hybrid in the Scout Set

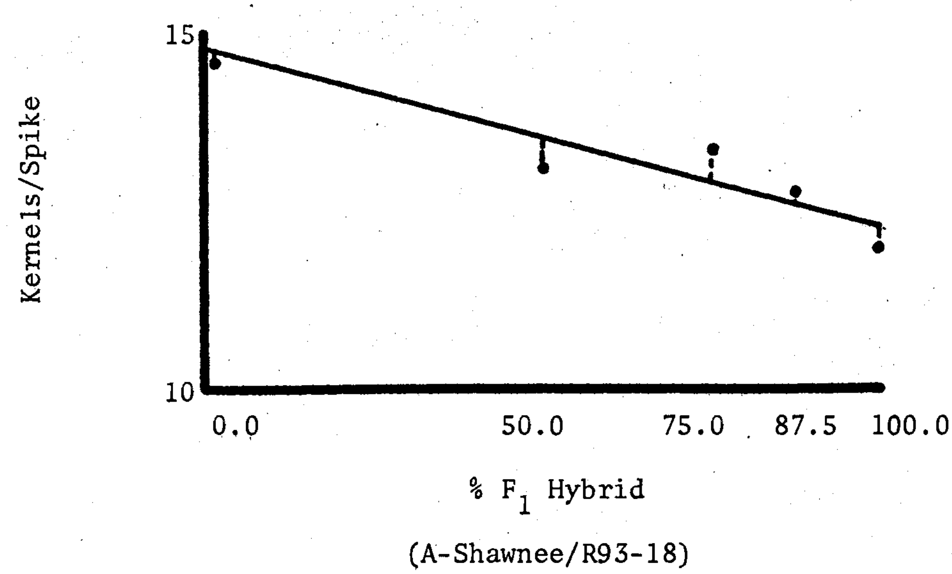

Figure 9. Regression Curve of Kernels/Spike on Percent Hybrid in the Shawnee Set

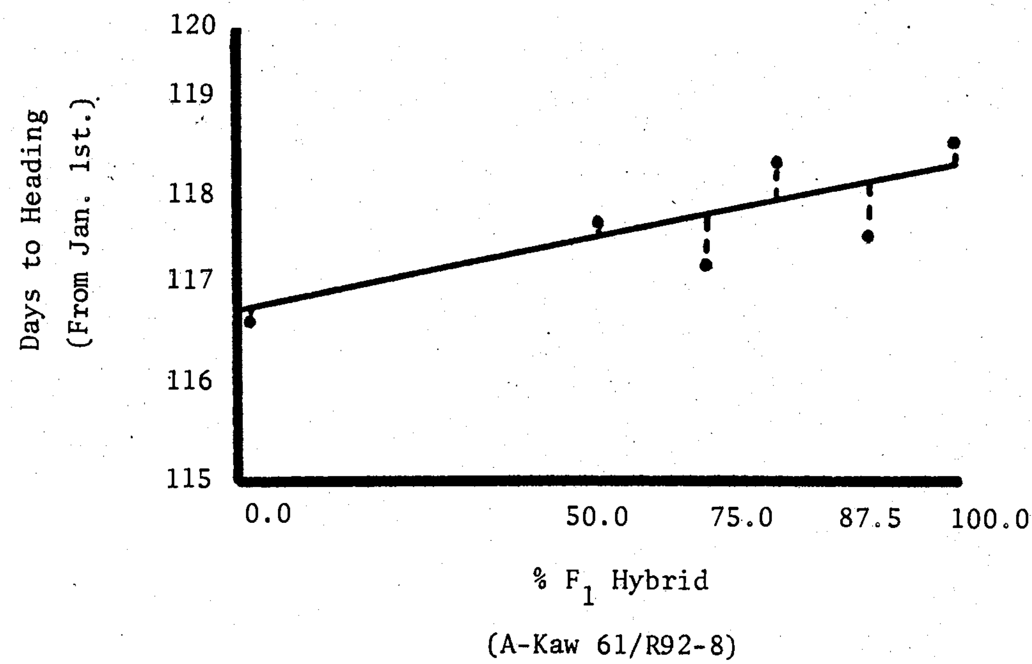

Figure 10. Regression Curve of Days to Heading on Percent Hybrid in the Kaw 61 Set

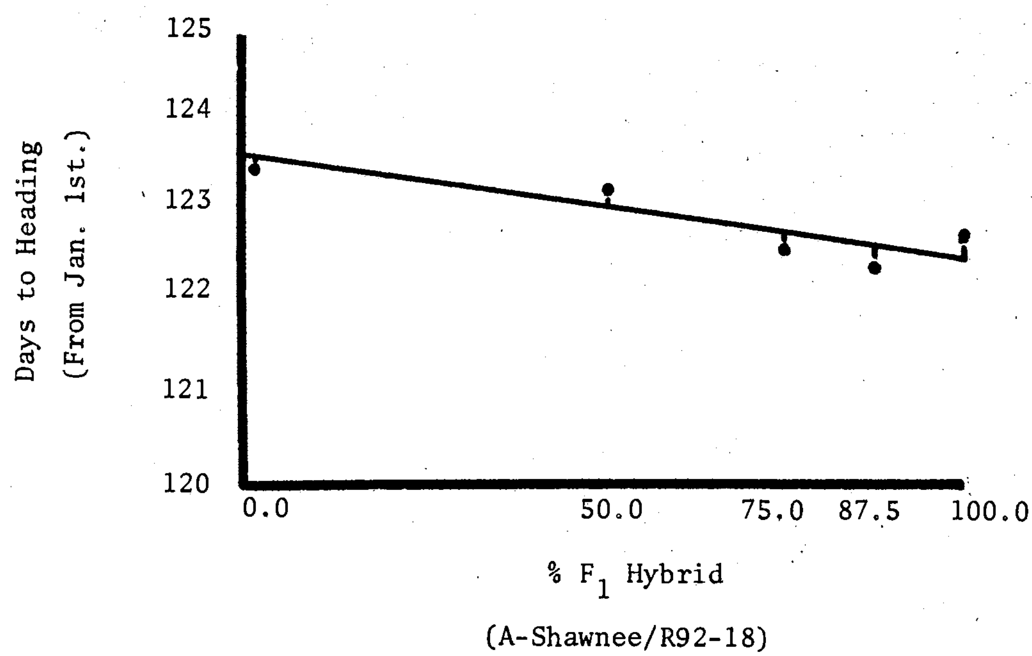

Figure 11. Regression Curve of Days to Heading on Percent Hybrid in the Shawnee Set

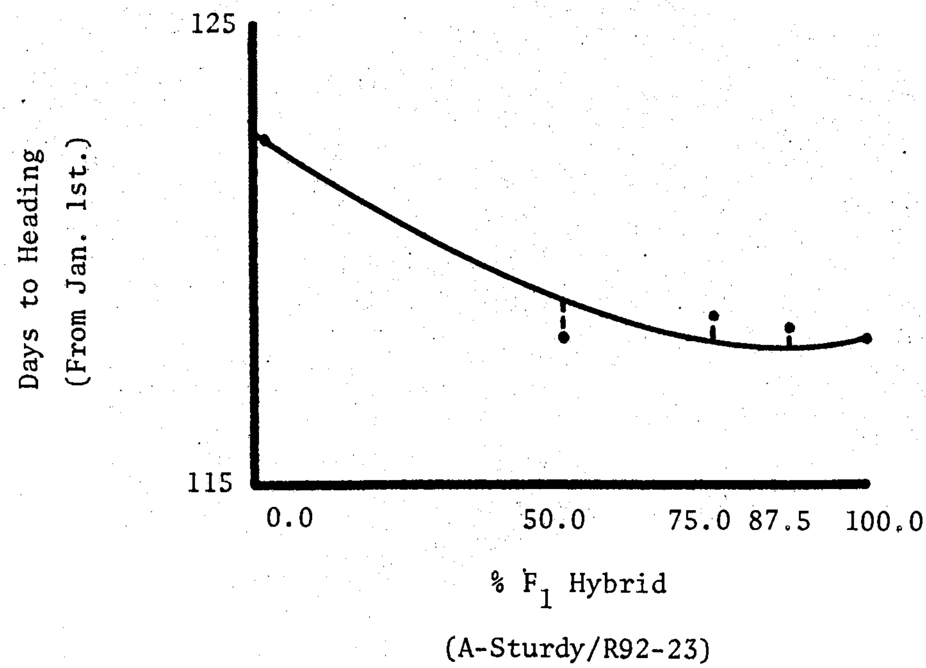

Figure 12. Regression Curve of Days to Heading on Percent Hybrid in the Sturdy Set

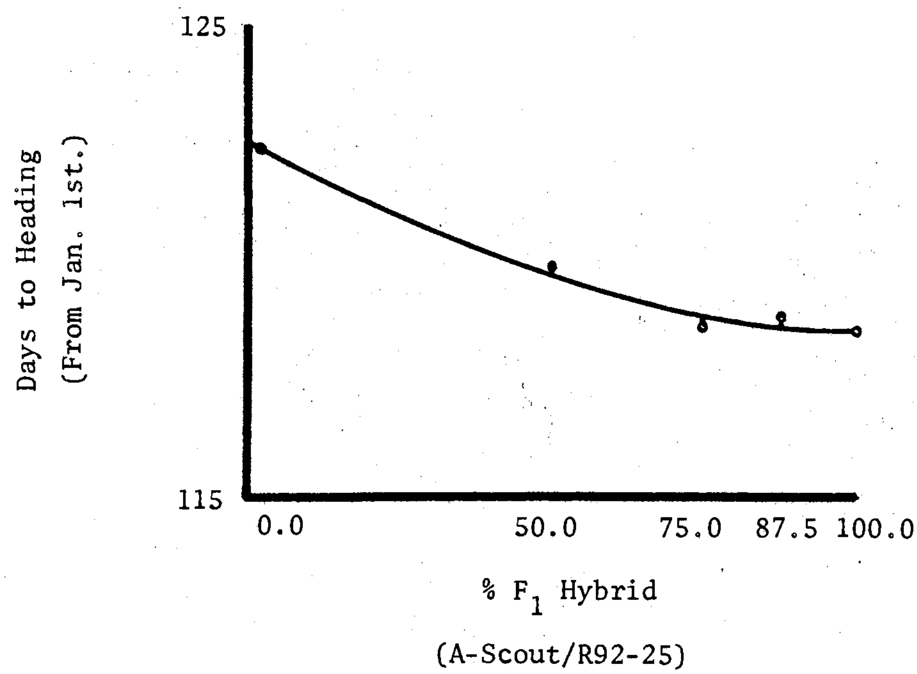

Figure 13. Regression Curve of Days to Heading on Percent Hybrid in the Scout Set

CHAPTER V

SUMMARY AND CONCLUSIONS

The objectives of this study were: (a) to determine the level of heterosis in five combinations of hard red winter wheat; and (b) to examine the performance of hybrid-parent mixtures for five important agronomic characters as a possibility of utilizing heterosis in other than pure hybrid populations.

Heterosis for five agronomic traits was examined for five hybrids developed by crossing male sterile lines with restorer lines. The hybrids were evaluated in replicated nursery plots at solid seeding rates. Characters analyzed were yield, kernel weight, kernels/spike, tiller number, and heading date. These five characters were also examined for each of five mixtures, consisting of blends of the F_1 hybrid and restorer parent, for each of five different sets of hybrids. The five mixtures examined for each hybrid set consisted of: 100% R-parent, 50% R-parent+50% F_1 hybrid, 25% R-parent+75% F_1 hybrid, 12.5% R-parent+87.5% F_1 hybrid, and 100 % F_1 hybrid.

Two of the hybrids involved in this study, A-Agent/R93-25 and A-Sturdy/R92-23, gave higher yields than Scout, the highest yielding check variety in the test. The best hybrid, A-Agent/R93-25, exhibited significant high parent heterosis for yield and outyielded Scout by 9%. All five hybrids exhibited significant mid-parent heterosis for kernel weight and two, A-Agent/R93-25 and A-Shawnee/R92-18, gave significant high-parent heterosis for this trait. Results obtained on kernel weight agree with those of other workers, and it was concluded that this trait was important in contributing to the heterotic yield of the hybrids.

Three of the hybrids in this study were significantly later in maturity than their earliest maturing parent, and one of these, A-Kaw 61/R93-8, was significantly later than its mid-parent with respect to heading date. None of the hybrids was significantly better than its respective mid-parent for kernels/spike or tiller number. One hybrid, A-Shawnee/R92-18, was significantly below its high-parent for both of these characters and produced significantly less kernels/spike than did its mid-parent. It was concluded from these results that tillering and kernels/spike were not of major importance for heterotic yields exhibited in this study.

If it is assumed that heterosis of 15 to 30% over the best parent is necessary for economically feasible commercial wheat hybrids, then the level of heterosis exhibited by the best hybrid in this test was not sufficient. However, other parental combinations might result in sufficient degrees of heterosis for commercial hybrid wheat production; therefore, early evaluation of parental lines would be useful in classifying potential parents in terms of expected hybrid performance.

The analysis of variance for the various mixtures indicated a linear response in yield for three of the five sets of mixtures as the percent hybrid increased, and two sets indicated no significant ordered response. The sets of mixtures showing significant linear responses in yield were A-Scout/R92-25, A-Agent/R93-25, and A-Kaw 61/R93-8, and they had respective regression coefficients of 1.1, .902, and .651 grams per plot. The sets of mixtures showing no significant ordered response with the unit increase in percent hybrid were A-Sturdy/R92-23 and A-Shawnee/ R93-18. These results indicate that some hybrid-parent mixtures might be expected to yield as much as pure hybrid populations. However, in this study the F_1 hybrids of the sets of mixtures having no ordered response did not exhibit significant heterosis for yield.

Only two sets of mixtures gave significant ordered responses for kernels/spike and tiller number with respect to the unit increase in percent hybrid. Kernels/spike for A-Shawnee/R93-18 decreased linearly and tiller number for A-Scout/R92-25, increased linearly as the percent hybrid of the mixtures was increased. It was concluded that kernels/ spike and tiller number, in general are not of major importance in contributing to the performance of hybrid-parent mixtures. Responses to heading date were significant in four sets of mixtures. The number of days required for maturity decreased in a linear fashion for one set, and in quadratic fashions for two of the sets. One set of mixtures had a linear increase in the number of days required for maturity as the percent hybrid increased.

Four out of the five sets of mixtures involved in this study gave significant ordered responses in kernel weight with respect to the increase in percent hybrid. One of the responses was linear with a regression coefficient of .04 grams per 1000 kernels, and three were curvilinear and reached maximum kernel weights at about 75% hybrid. In this study, kernel weight was found to be of major importance in contributing to grain yields. Therefore, these results suggest that for certain hybrids any seed mixture within the range of about 75% hybrid to 25% R-parent, would be expected to be the most economically feasible in utilizing hybrid vigor in reducing the cost of producing wheat hybrids for commercial use.

The scope of this study was preliminary in nature, to provide insight into the possible uses of hybrid-parent mixtures in minimizing the extra cost of producing hybrid wheat. These findings indicate that hybrid-parent mixtures of certain hybrids can be used successfully by wheat breeders in utilizing hybrid vigor in other than pure hybrid populations in producing wheat hybrids for commercial use.

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TABLE V

PARENTAL AND F_1 MEANS AND HYBRID-PARENT DEVIATIONS FOR HEADING DATE

F_1 Hybrid or Parent	Rank (earliest to latest)	Heading Date	Hybrid Deviations Mid-Parent	Hybrid Deviations High-Parent
Kaw 61	1	116.00	---	---
A-Sturdy/R92-23	2	116.33	2.17**	0.17
Sturdy	3	116.50	---	---
R93-8	4	116.83	---	---
Scout	4	116.83	---	---
A-Scout/R92-25	6	118.67	0.91*	-1.84**
A-Kaw 61/R93-8	6	118.67	-2.25**	-2.67**
R92-23	8	120.50	---	---
A-Agent/R93-25	9	120.67	0.91*	0.83
Agent	10	121.50	---	---
R93-25	11	121.67	---	---
Shawnee	12	121.83	---	---
R92-25	13	122.33	---	---
A-Shawnee/R93-18	14	122.83	-0.16	-1.00*
R93-18	15	123.50	---	---

*Hybrid-parent contrast is significant at the .05 level of probability.

**Hybrid-parent contrast is significant at the .01 level of probability.

TABLE VI

PARENTAL AND F_1 MEANS AND HYBRID-PARENT DEVIATIONS FOR GRAIN YIELD

F_1 Hybrid or Parent	Rank (highest to lowest)	Grain Yield (gms/plot)	Hybrid-Deviations	
			Mid-Parent	High-Parent
A-Agent/R93-25	1	444.5	85.4**	73.7**
A-Sturdy/R92-23	2	430.7	23.0	10.0
R92-23	3	420.7	---	---
Scout	4	406.5	---	---
Sturdy	5	394.7	---	---
A-Scout/R92-25	6	391.7	44.8*	-14.8
R93-25	7	370.8	---	---
Kaw 61	8	369.2	---	---
A-Kaw 61/R93-8	9	361.3	29.9	- 7.9
Agent	10	347.3	---	---
Shawnee	11	310.2	---	---
R93-8	12	293.5	---	---
R92-25	13	287.3	---	---
R93-18	14	281.3	---	---
A-Shawnee/R92-18	15	279.5	-16.3	-30.7

*Hybrid-parent contrast is significant at the .05 level of probability.

**Hybrid-parent contrast is significant at the .01 level of probability.

TABLE VII

PARENTAL AND F_1 MEANS AND HYBRID-PARENT DEVIATIONS FOR KERNEL WEIGHT

F_1 Hybrid or Parent	Rank (highest to lowest)	1000 Kernel Weight	Hybrid Deviations	
			Mid-Parent	High-Parent
A-Sturdy/R92-23	1	26.71	2.27**	0.21
R92-23	2	26.50	---	---
A-Agent/R93-25	3	24.25	2.79**	2.54**
Scout	4	23.25	---	---
A-Scout/R92-25	5	23.17	1.48*	-0.08
Sturdy	6	22.38	---	---
A-Kaw 61/R93-8	7	22.25	2.40**	1.00
A-Shawnee/R93-18	8	21.92	2.80**	1.88**
Agent	9	21.71	---	---
Kaw 61	10	21.25	---	---
R93-25	11	21.21	---	---
R92-25	12	20.13	---	---
R93-18	13	20.04	---	---
R93-8	14	18.46	---	---
Shawnee	15	18.21	---	---

*Hybrid-parent contrast is significant at the .05 level of probability.

**Hybrid-parent contrast is significant at the .01 level of probability.

TABLE VIII

PARENTAL AND F_1 MEANS AND HYBRID-PARENT DEVIATIONS FOR KERNELS/SPIKE

F_1 Hybrid or Parent	Rank (highest to lowest)	Kernels/ Spike	Hybrid Deviations	
			Mid-Parent	High-Parent
Agent	1	17.12	---	---
Kaw 61	2	16.46	---	---
Sturdy	3	16.32	---	---
A-Agent/R93-25	4	15.92	-0.03	-1.20
R92-23	5	15.69	---	---
A-Sturdy/R92-23	6	15.30	-0.71	-1.02
R92-25	7	14.85	---	---
R93-25	8	14.78	---	---
R93-18	9	14.57	---	---
Scout	10	14.52	---	---
A-Scout/R92-25	11	14.40	-0.29	-0.45
A-Kaw 61/R93-8	11	14.40	-0.42	-2.06
Shawnee	13	13.71	---	---
R93-8	14	13.18	---	---
A-Shawnee/R93-18	15	12.21	-1.93*	-2.36**

*Hybrid-parent contrast is significant at the .05 level of probability.

**Hybrid-parent contrast is significant at the .01 level of probability.

TABLE IX

PARENTAL AND F_1 MEANS AND HYBRID-PARENT DEVIATIONS FOR TILLER NUMBER

F_1 Hybrid or Parent	Rank (highest to lowest)	Tiller Number	Hybrid Deviations	
			Mid-Parent	High-Parent
Shawnee	1	78.00	---	---
R93-8	2	75.50	---	---
Scout	3	63.33	---	---
R93-25	4	74.67	---	---
A-Scout/R92-25	5	73.67	5.84	-1.50
A-Agent/R93-25	6	72.17	5.42	-2.50
A-Kaw 61/R93-8	7	71.83	1.00	-3.67
Sturdy	8	68.83	---	---
A-Sturdy/R92-23	9	66.33	0.25	-2.50
Kaw 61	10	66.17	---	---
A-Shawnee/R93-18	11	65.83	-3.25	-12.17**
R92-23	12	63.33	---	---
R92-25	13	60.50	---	---
R93-18	14	60.17	---	---
Agent	15	58.83	---	---

*Hybrid-parent contrast is significant at the .05 level of probability.

**Hybrid-parent contrast is significant at the .01 level of probability.

TABLE X

COMPARISON OF MEANS FOR YIELD OF HYBRIDS, PARENTS, AND HYBRID-PARENT MIXTURES

Hybrid, Parent, or Mixture	Rank (highest to lowest)	Yield (gms/plot)
A-Agent/R93-25+R93-25 (87.5%:12.5%)	1	470
A-Agent/R93-25	2	445
A-Agent/R93-25+R93-25 (75.0%:25.0%)	3	444
A-Sturdy/R92-23	4	431
A-Sturdy/R92-23+R92-23 (50.0%:50.0%)	5	427
R92-23	6	421
A-Agent/R93-25+R93-25 (50.0%:50.0%)	7	413
Scout	8	407
A-Sturdy/R92-23+R92-23 (75.0%:25.0%)	9	402
Sturdy	10	395
A-Scout/R92-25+R92-25 (87.5%:12.5%)	11	393
A-Scout/R92-25	12	392
A-Sturdy/R92-23+R92-23 (87.5%:12.5%)	13	388
A-Scout/R92-25+R92-25 (75.0%:25.0%)	14	379
R93-25	15	371
Kaw 61	16	369
A-Kaw 61/R93-8+R93-8 (75.0%:25.0%)	17	366
A-Kaw 61/R93-8	18	361
A-Scout/R92-25+R92-25 (50.0%:50.0%)	19	353
A-Kaw 61/R93-8+R93-8 (50.0%:50.0%)	20	352
A-Kaw 61/R93-8+R93-8 (87.5%:12.5%)	21	348
Agent	22	347
A-Shawnee/R92-18+R92-18 (75.0%:25.0%)	23	312
Shawnee	24	310
A-Shawnee/R92-18+R92-18 (50.0%:50.0%)	25	308
A-Shawnee/R92-18+R92-18 (87.5%:12.5%)	26	302
R93-8	27	294
R92-25	28	287
R92-18	29	281
A-Shawnee/R92-18	30	280

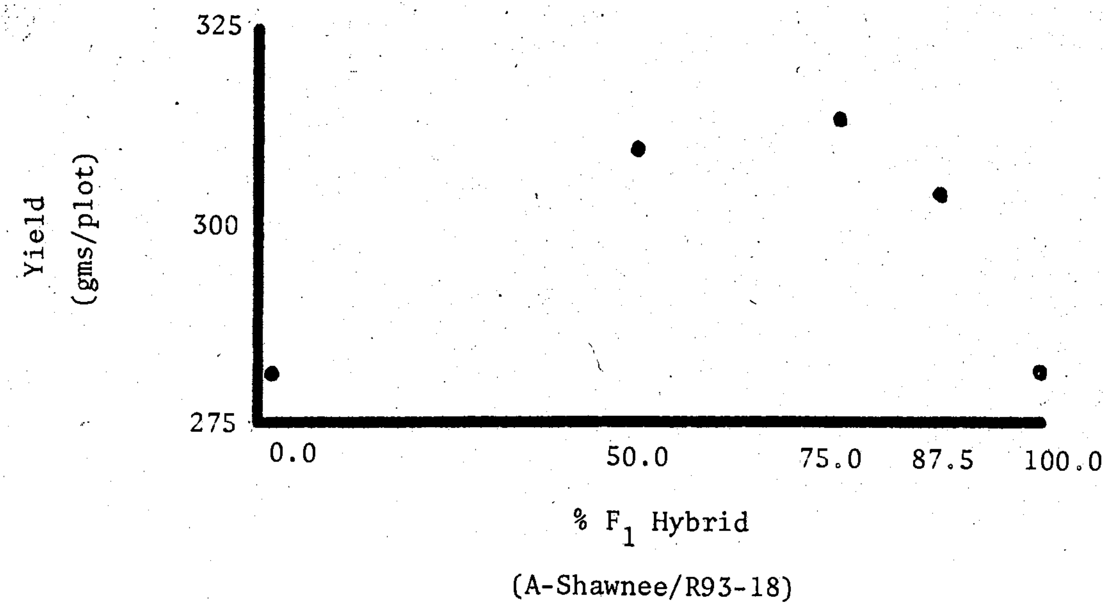


Figure 14. Yield of the Various Hybrid-Parent Mixtures of the Shawnee Set

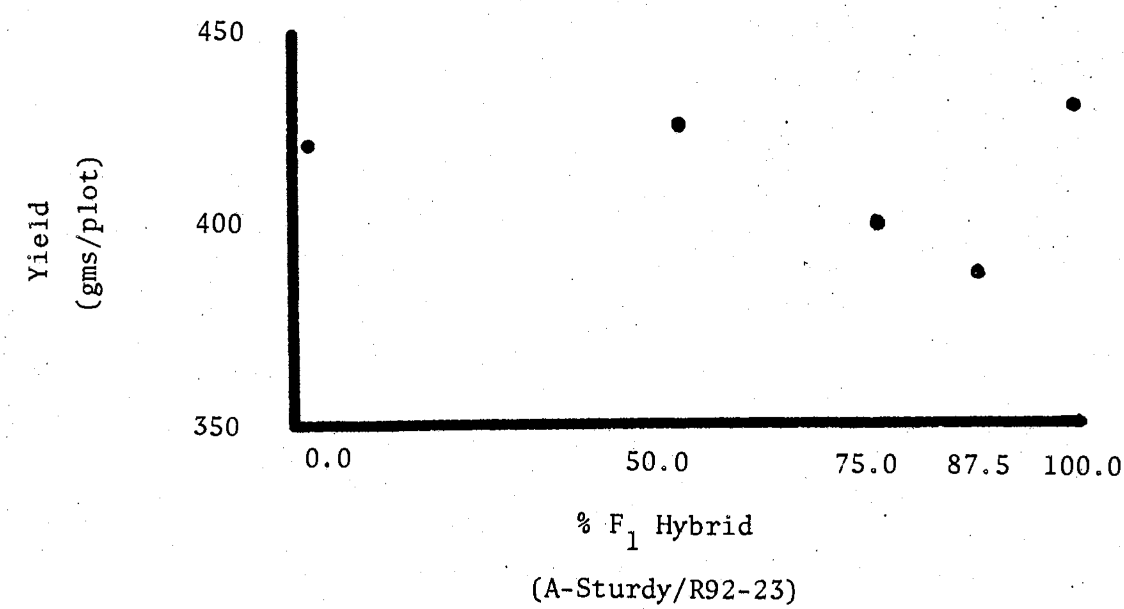


Figure 15. Yield of the Various Hybrid-Parent Mixtures of the Sturdy Set

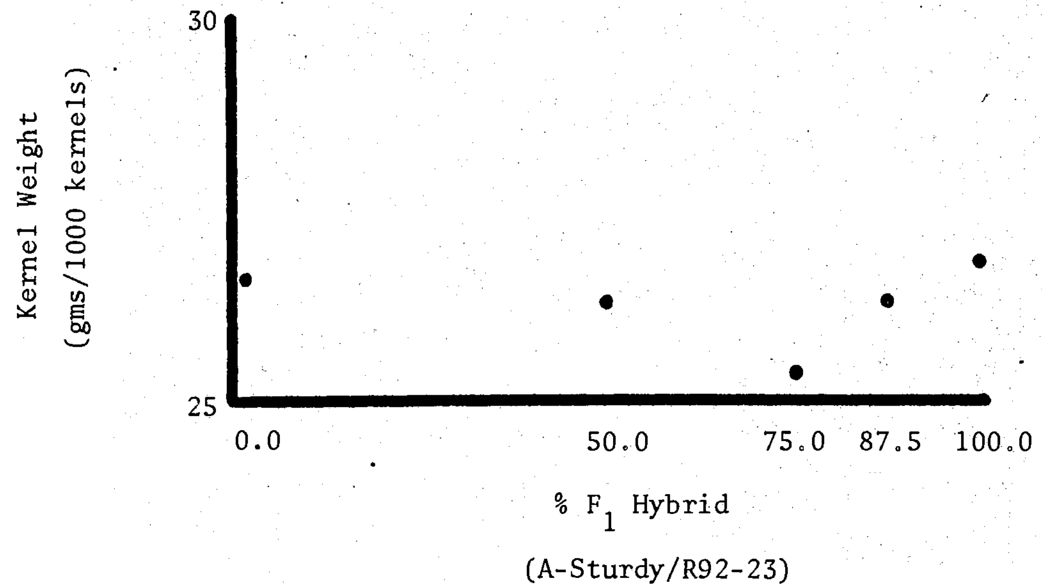


Figure 16. Kernel Weight of the Various Hybrid-Parent Mixtures of the Sturdy Set

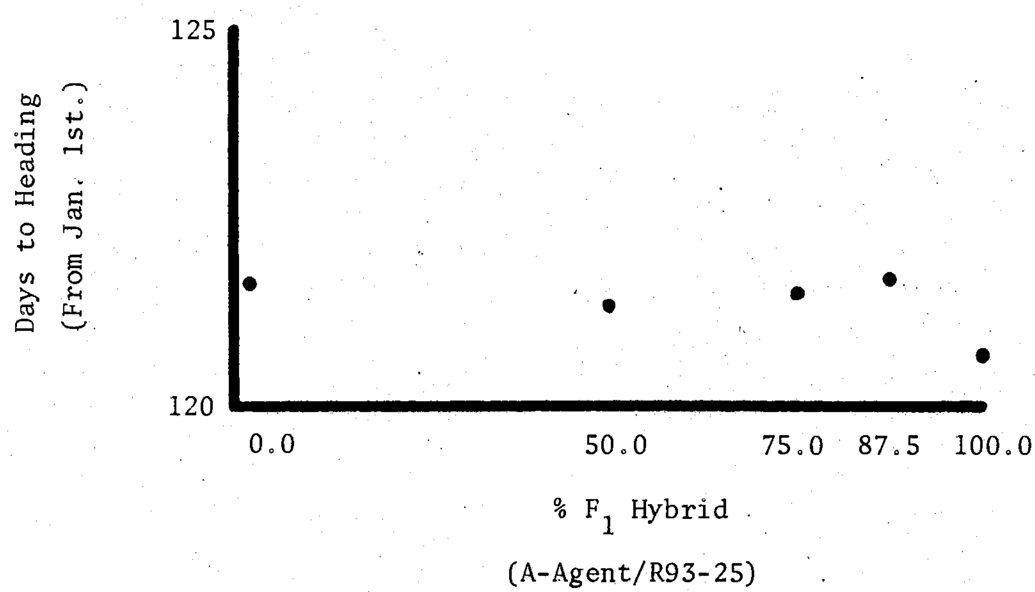
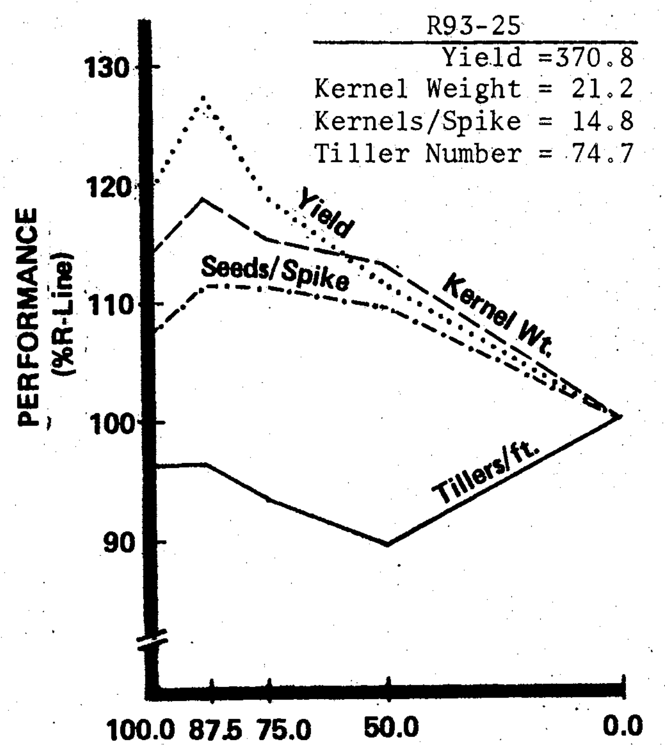


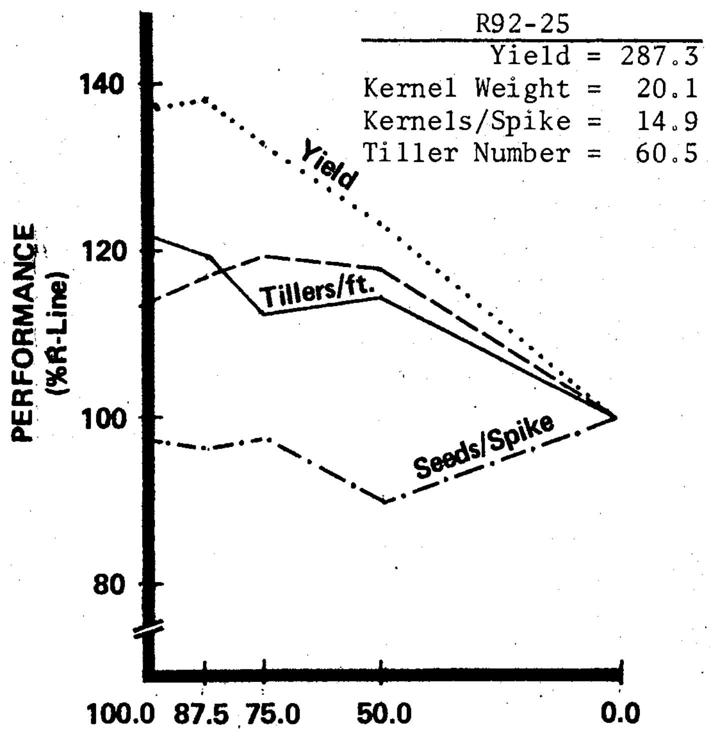
Figure 17. Heading Date of the Various Hybrid-Parent Mixtures of the Agent Set



% Hybrid

(A-Agent/R93-25)

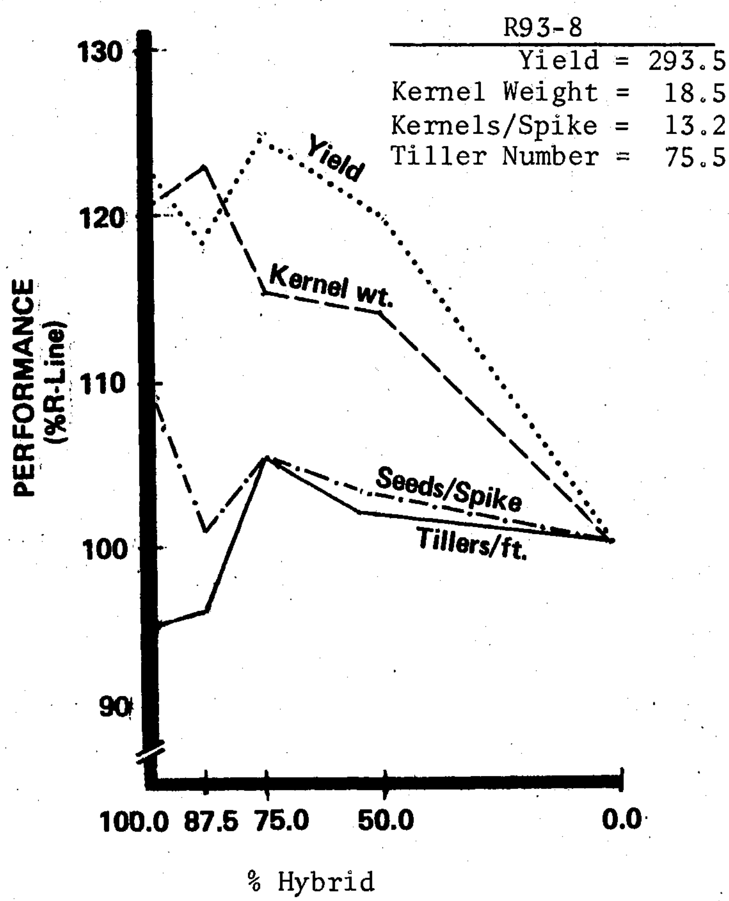
Figure 18. Yield and Components of Yield of the Various Hybrid-Parent Mixtures of the Agent Set Expressed as Percent of the R-Line



% Hybrid

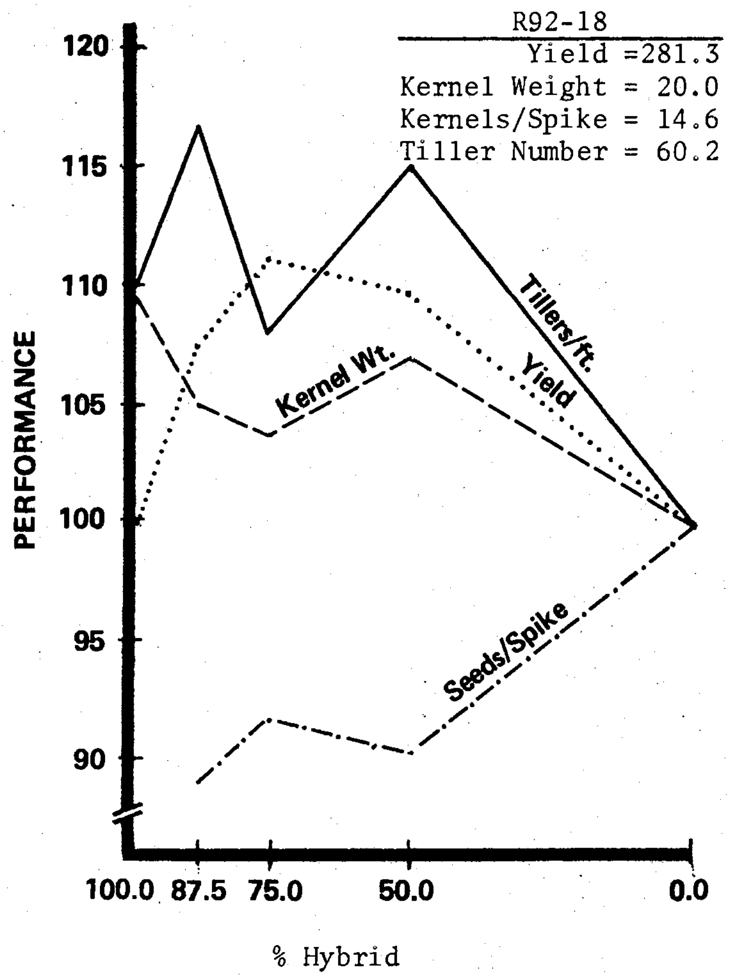
(A-Scout/R92-25)

Figure 19. Yield and Components of Yield of the Various Hybrid-Parent Mixtures of the Scout Set Expressed as Percent of the R-line



(A-Kaw 61/R93-8)

Figure 20. Yield and Components of Yield of the Various Hybrid-Parent Mixtures of the Kaw 61 Set Expressed as Percent of the R-line



(A-Shawnee/R92-18)

Figure 21. Yield and Components of Yield of the Various Hybrid-Parent Mixtures of the Shawnee Set Expressed as Percent of the R-line

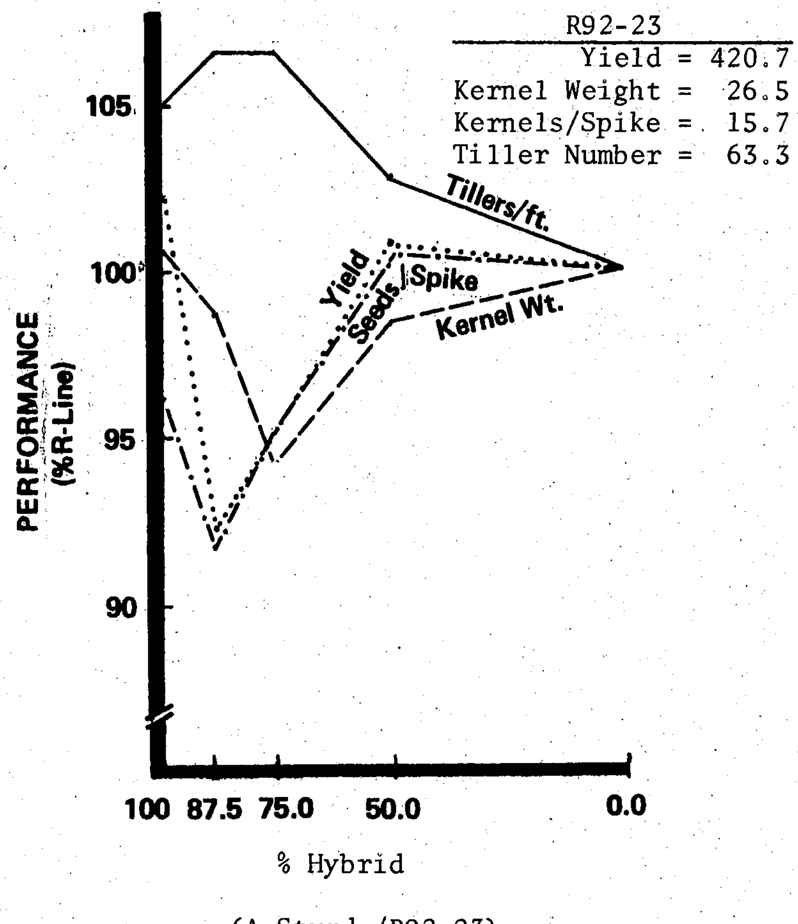


Figure 22. Yield and Components of Yield of the Various Hybrid-Parent Mixtures of the Sturdy Set Expressed as Percent of the R-line

VITA

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Master of Science

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