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MEANS AND VARIANCES OF EARLY GENERATION BULKED POPULATIONS IN SPRING WHEAT AS PREDICTORS OF DERIVED LINE PERFORMANCE

BY

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This thesis is approved as a creditable and independent investigation by a candidate for the degree, Doctor of Philosophy, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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MEANS AND VARIANCES OF EARLY GENERATION BULKED POPULATIONS IN SPRING WHEAT AS PREDICTORS OF DERIVED LINE PERFORMANCE.

Abstract

ZAHOOR A. SWATI

Fifteen crosses involving three high and three low-yielding hard red spring wheats, (Triticum aestivum L.), adapted inbred lines to the production conditions of South Dakota were used to assess early generation means and variances in identifying bulked populations that produced high-yielding derived lines. In addition, different generations were evaluated to determine which would best identify crosses with the greater potential for producing segregates having high-yielding ability. Traits examined in early generation bulked and spaced-planted populations and derived lines were: 1) grain yield; 2) time to heading; and, 3) plant height.

Means and variances of early generation bulked populations were moderately successful in detecting those crosses which produced superior derived lines. The variance was some what more effective. Most of the high-yielding and early-heading lines were obtained from crosses identified as superior either by mean, variance or both in F_3 and F_4 in 1985 and 1986, respectively.

None of the parameters, however, was successful in predicting shorter derived lines.

Populations producing the largest number of high-yielding derived lines were obtained from crosses with both parents high-yielding. Derived lines with the lower mean yield were from crosses involving low-yielding parents. The proportion of high-yielding derived lines from high x low crosses was the same as from the high x high crosses in 1985.

The derived lines obtained from crosses involving SD2861 as one of the parents showed high mean yields and headed early. Crosses involving Guard also showed a large number of high-yielding derived lines.

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INTRODUCTION

Cultivars with improved genetic potential for yield and other economically important traits are the goal of plant breeding programs. For wheat, (Triticum aestivum L.), due to its autogamous method of reproduction, cultivars are homozygous inbred lines. Breeding programs are modifications on the basic scheme of hybridization, selection, and replicated trial testing. Any technique increasing the efficiency in identifying transgressive segregates would improve the selection step in the breeding program.

The bulk breeding method is frequently used with wheat. With this method early generations of hybrid populations are harvested in bulk with limited artificial selection applied. Populations are maintained in bulk until the F_5 to F_8 generation when inbred lines are selected for further testing. Early generation testing has been proposed as a method of identifying bulked populations likely to produce a high frequency of transgressive segregates. This would allow the breeder to maintain the promising crosses and discard the undesirable ones in early generations. Previous reports on early generation yield testing of bulked populations and subsequent inbred line performance provides mixed results. In general, research has centered on comparing bulked population mean yields to mean yields of derived lines from the populations. Limited research has been reported comparing means and variances of bulked populations to subsequent line performance. The principal objectives of this study were to: 1. assess the use of early generation means and variances in identifying bulked populations producing greater-yielding inbred lines; and, 2. determine which generation would best identify crosses with a high potential for producing greater-yielding inbred lines.

LITERATURE REVIEW

Prediction of Progeny Performance

Due to constraints of time and resources, plant breeders have been interested in identifying bulked populations producing a high frequency of superior transgressive segregates. Efficiency in breeding self-pollinated crops could be increased if early generation bulked populations producing the greatest number of superior inbred lines could be identified.

Busch et al. (1974) evaluated F_4 and F_5 bulked populations, parents, and 21 randomly selected F_2-derived F_5 and F_6 lines of hard red spring wheat to predict random line performance based on bulk and midparental yields. They found the average performance of the randomly selected lines and average of the highest five lines were highly correlated with the mean of F_4 and F_5 bulks, $r = 0.90$ and $r = 0.88$, respectively. They concluded that the mean yields of F_4 or F_5 bulks could be used effectively to predict populations producing the greater proportion of high-yielding lines.

Cregan and Busch (1977) tested the value of midparent, F_1, and F_2 through F_5 bulked generation yields as predictive criteria for identifying crosses producing a high proportion of superior yielding F_5 lines. The mean yield of the F_2 and F_3 effectively identified 56 to 67% of the F_5 lines which yielded at least two standard deviations above the overall line mean. They also found that crosses with greater genetic variance were more likely to contribute high-yielding lines.

Immer (1941) grew bulked F_2, F_3, and F_4 generations of six barley (Hordeum vulgare L.) crosses in replicated yield trials to determine their efficiency in detecting the better crosses. The two populations that produced the highest yield in F_2 and F_3 were also the highest in F_4, while two other crosses were relatively low yielding in all generations. He suggested the average yield performance of different crosses in later generations could be determined by replicated yield trials in the F_2 or F_3 generations. Such yield trials would be useful in discarding crosses in an early generation because of the low probability of their producing high-yielding inbred lines.

Harrington (1940) conducted replicated yield trials with bulked unselected seed of ten wheat crosses in the F_2 and six crosses in the F_3 generations. The yield of the latter six crosses was determined by replicated rod row yield tests of selected lines in the F_6, F_7, and F_8 generations. Like Immer, he concluded that replicated tests of bulked F_2 populations could be used to indicate the yielding potential of wheat crosses, and that tests of bulked F_3 populations were equally efficient.

Harlan et al. (1940) studied 379 barley crosses from 28 parents for seven generations. Individual plant selections for yield tested in the F_9 generation were increased from the F_8 generation. The yields of the bulked populations before plant selections aptly indicated crosses with high-yielding segregates. The authors felt that low-yielding crosses could have been discarded prior to plant selection, allowing the breeding program to concentrate its resources on crosses with a greater probability of producing superior progeny.

Rosielle (1983) used computer simulation techniques to examine the effect of genetic variance and the correlation between mean and genetic variance on the efficiency of bulk yield testing procedures. He varies the following parameters in his model: between bulk heritability, genetic variance ratio, variance of the within bulk genetic variance, correlation between bulk means and within bulk genetic variances, and selection intensity among bulks. His goal was to determine the combination of parameters giving maximum potential gain. Maximum potential gain was defined as the genetic gain which would be achieved if the bulks which maximize genetic advance were chosen for plant selection. Maximum potential gains increased with increasing mean genetic variance within bulks but showed only a slight response to increasing variation of the within bulk genetic variance. For a 16-fold increase in mean genetic variance within bulks the maximum potential gain almost doubled. However, of an 8-fold increase in the ratio of variation of the within bulk genetic variance the maximum potential gain increased only by 2% and 13%. Maximum potential gains were reduced as the correlation between bulk mean and within bulk variance changed from positive to negative and became more negative but the effects were small. The optimum gain as a percentage of maximum potential gain was not affected. He concluded that bulk yield testing would generally provide high positive genetic gains for a wide range of population parameters.

Forty five crosses from a 10 parent diallel in soybeans (Glycine max L.) were studied by Leffel and Hanson (1961) in the F_2 and F_3 bulked populations, F_1, F_2 spaced-planted populations, and F_2-derived F_3 lines. Mean yields from these generations were analyzed to determine the average and specific contributions of parental yields to mean progeny yield and the presence or absence of epistatic, dominant, and additive gene actions. The performance of parents or their crosses in early generations of bulked populations were reliable predictors of the performance of lines obtained from the crosses in the F_3 generation.

The effectiveness of selection for yield and bread making quality parameters on three F_3 populations of hard red spring wheat was studied by Briggs and Shebeski (1970). They examined the performance of F_3 selections using the mean yield of a population of randomly derived F_5 lines. The highest-yielding F_5 populations were derived from F_3 lines which were higher yielding on a plot basis and higher yielding than adjacent control plots.

Smith and Lambart (1968) investigated the predictive value of parental and early generation bulked population means with respect to yield and kernel weight of six spring barley based on F_5 line performance. They found that crosses having the best yielding performance in each generation were also those that produced superior F_5 lines. The F_3, F_4, F_5 generations were generally all reliable predictors of crosses with high yield potential. Also, the F_2, F_3, F_4, and F_5 generations were similar in identifying the crosses from which high kernel weight segregates could be selected.

Nass (1979) evaluated the F_1, F_2 and midparental yield of spring wheat as potential aids in identifying superior crosses early in the breeding program. Based on his observations, he recommended the use of midparental, F_1, and F_2 yield tests for a given set of crosses to effectively maintain the superior crosses in the breeding program.

McVetty and Evans (1980) used three spring wheat crosses to evaluate the use of physiological and/or morphological parameters alone or in combination on F_2 plants as selection criteria to identify high-yielding F_4 bulked populations. The results indicated that single F_2 measurements of source capacity, sink capacity, or plant morphology all identified high yield potential in the F_2.

Fowler and Heyne (1955) tested parents, F_3, F_4, and F_5 bulk generations, of 45 hard red winter wheat crosses, in replicated trials to predict the yield of 7 or 8 randomly selected lines from each F_5 bulk. They concluded that early generation tests and parental performance were of no value for predicting yield of random pure line selections. Plant height and maturity of selected lines, however, were predictable from bulk trials.

Continued selection in the F_2, F_3, and F_4 generations of 11 bulk hybrid barley populations for vigorous plants with large, well-filled, disease-free heads was practiced by Atkins (1953). Evaluation of the selected populations for yield, heading date, maturity date, plant height and lodging resistance in comparison with their respective bulked populations revealed that selection in F_2, F_3, and F_4 based on several plant characteristics contributing to yield was not effective in isolating high-yielding lines. Kalton (1948) found maturity, plant height and lodging to be relatively constant in the bulked F_2, F_3, and F_4 generations of 25 soybean crosses, but yield differences were inconsistent from generation to generation.

Types of Crosses

Parents used in hybridization programs are usually selected to complement each other for the trait under improvement. In many cases one parent of a cross is adapted to the local environment, while the other parent exhibits an intense level of the trait under improvement. This second parent many times is low-yielding. Plant breeders, then must make crosses among high and low-yielding parents.

Busch et al. (1974) studied 25 populations resulting from crosses among four high and four low-yielding parents of hard red spring wheat in three environments. He found that high-yielding lines were obtained most often from crosses between high performing parents. The highest-yielding line, however, came from a high x low cross. Such results suggest that selection within a cross may be less important than mean cross performance in determining which crosses produce the best genotypes.

Gene action involved in the inheritance of lint index was investigated by Ramey (1963) in the parental, F_1 and F_2 generations of 28 populations of cotton (Gossypium hirsutum L.) which resulted from the crossing of eight lines, four of which exhibited low and four high lint indices. Dominant gene action was involved in populations resulting from crosses of high x high and low x low parents. Epistasis was noted in populations resulting from crosses of high x low lines, and he suggested dominance was also operative in this group. F_1 means generally exceeded midparental values. Epistasis, where found, resulted in the rapid regression of the F_2 mean toward the midparent.

Green (1948) evaluated the inheritance of combining ability in the F_2 generation of three maize (Zea mays L.) single crosses representing crosses of high x high, high x low, and low x low combining inbred lines. A higher frequency of good combining F_2 segregates were found in the progeny of high x high crosses than in either the high x low or the low x low crosses. Lonnquist (1953) selected three high and three low yielding maize lines, based on test crosses, as parents for high x high, high x low and low x low crosses in an attempt to evaluate gene action. The mean yield of the high x high hybrids was superior to that of the high x low or low x low hybrids.

Johnson and Hayes (1940) tested maize hybrids from combinations of two groups of high and two groups of low-yielding inbred lines. They found that the proportion of high-yielding hybrids from the high x low group was equal to the high x high group. Three high x low hybrids yielded more and two less than any of the high x high or low x low hybrids.

Lonnquist and Lindsey (1964) reported a linear trend for increased yield in F_1 hybrids from the low x low to high x high crosses of maize lines selected for yield as selfed lines. However, when parental lines were selected on the basis of an unrelated top cross tester the high x low hybrids outyielded the high x high and low x low hybrids. Lonnquist (1968) also selected high and low yielding maize lines based on their performance in hybrid combinations with their original parent population. Again he reported a linear trend for yield of hybrids, increasing from low x low to high x high crosses.

Schrader et al. (1966) reported maize hybrids to be intermediate to their parents in nitrate reductase activity when comparing crosses made high x high and high x low. Significant heterosis over midparent was found in some of the low x low hybrids.

Kalton and Leffel (1955) studied the combining ability of orchardgrass (Dactylis glomerata L.) by testing single cross hybrids. The parents were selected for high and low forage yield and panicle number. These parents were crossed in all combinations. The high x low hybrids were intermediate for panicle number when compared to the high x high and low x low hybrids. Forage yields of the high x low hybrids were approximately the same as the high x high hybrids.

Langham (1949) reported the use of diverse parents in crosses of sesame (Sesamum indicum L.) to obtain transgressive segregates. Disease and insect resistance were increased as well as yield by crossing the most desirable parent with the least desirable for the characteristics under improvement. This early work with transgressive segregation led him (1961a, 1961b) to propose the high x low method of crop improvement. He hypothesized that genes for maximum expression of a characteristic, either high or low, may be closely associated with suppressor genes which prevent their maximum expression. Thus a suppressor for high expression may then become an enhancer for low expression of a characteristic. By crossing high x low representatives of a population and growing large F_2 populations, favorable genes might recombine with new modifying genes, resulting in transgressive segregation.

Smith (1966) suggested that parents of a cross should exhibit reasonably favorable expressions of the desired trait to obtain transgressive segregates. He concluded that distantly related parents may enhance selection because the characteristics may be controlled by differing sets of genes.

MATERIALS AND METHODS

Fifteen crosses involving three high and three low-yielding hard red spring wheats adapted to the production conditions of South Dakota were used in this investigation. Parents were SD2861, 'Guard', 'Protor', 'Alex', 'Eureka', and 'Pondera'. The origin and a summary of their agronomic characteristics are presented in Table 1. In replicated yield trials conducted in eastern South Dakota in 1982 and 1983 yearly averages of the three high-yielding cultivars were 2.37 and 2.47 Mg ha^{-1}; while the low yielding cultivars averaged 2.06 and 2.22 Mg ha^{-1} per year.

The classification of yield of the parents, as given in Table 1, provided the basis for the 15 crosses. Crosses were placed into three groups according to parental performance: high-yielding parent x high-yielding parent (high x high), high-yielding parent x low-yielding parent (high x low), and low-yielding parent x low-yielding parent (low x low). Each cross was assigned a number to facilitate the discussion and are referred to henceforth by number rather than pedigree (Table 2).

Parents were crossed in all combinations by K. Sellers excluding reciprocals in 1982. The F_2, F_3, and F_4 bulked populations for each cross was produced at Brookings, with no overt selection in 1984. Ten-gram samples of seed of the bulked populations from all three generations were taken for spaced-planted populations, and random samples of 15 heads from F_2, F_3,

Table 1. Agronomic characteristics and origin of the parental lines.

		Characteristics		
Parents	Origin	Heading Date	Plant Height	Yield
SD2861	SD	Early	Short	High
Guard	SD	Early	Short	High
Protor	NK[a]	Early	Short	High
Eureka	SD	Late-Medium	Tall	Low
Alex	ND	Late-Medium	Tall	Low
Pondera	MT	Early	Medium	Low

[a] Northupking

Table 2. Number, Parents, and designation of the 15 crosses.

Cross Number	Parent1	Parent2	Cross Designation
1	SD2861	Guard	High x High
2	SD2861	Protor	High x High
3	Guard	Protor	High x High
4	SD2861	Eureka	High x Low
5	SD2861	Alex	High x Low
6	SD2861	Pondera	High x Low
7	Guard	Eureka	High x Low
8	Guard	Alex	High x Low
9	Guard	Pondera	High x Low
10	Protor	Eureka	High x Low
11	Protor	Alex	High x Low
12	Protor	Pondera	High x Low
13	Eureka	Alex	Low x Low
14	Eureka	Pondera	Low x Low
15	Alex	Pondera	Low x Low

and F_4 bulked populations were also drawn for single rows in 1985. The remaining seed was bulked. Bulked and spaced-planted populations were grown to obtain the means and variances of the crosses, respectively. These parameters were used to evaluate the performance of the crosses in early generations and then to determine the relationship between the performance in early generations and subsequent derived line performance.

Bulked Populations

Parents, F_3, F_4, and F_5 bulked populations were planted at Brookings (Vienna silt loam) on April 19, 1985. Due to insufficient seed, crosses 12 and 14 in the F_3 and F_4 generations, respectively, were not included. The experimental design was a randomized complete block with three replications. The plot size was 6.1 by 1.5 m which was trimmed to a length of 4.3 m for harvest. The seeding rate was approximately 278 seed per m^2 and the distance between two adjacent rows was 17.8 cm.

Ramrod and Bronate were applied at the rates of 5.6 Kg ha^{-1} and 0.56 Kg ha^{-1}, for grassy and broad leaf weed control, respectively. In addition some hand weeding was done. The plots were fertilized with ammonium nitrate for a yield goal of 4 Mg ha^{-1}.

Data were recorded for each plot on the following:

1. Time to heading - the date when 50 percent of the

spikes had emerged from the boot (Feekes scale stage 10.3) and recorded as number of days.

2. Plant height - recorded in centimeters from the ground level to the tip of the main tiller excluding awns.
3. Grain yield - weight of grain in grams harvested from each plot.

Spaced-Planted Populations

Spaced-planted populations including parents and the three generations of the 15 crosses (except crosses 12 and 14 of F_3 and F_4 generations, respectively) were planted on April 19, 1985. Plot size, fertilizer, and herbicide regimes were the same as for the bulked populations. The seeding rate used was approximately 800 seeds, mixed with 1600 winter wheat seeds, per plot to produce approximately 87 spring wheat plants per m^2. The winter wheat was included to compete with the spring wheat and reduce weed problems. Data for time to heading, plant height, and yield were recorded on an individual plant basis for 30 randomly selected plants that were tagged at the time of heading. Random samples of 15 heads from each cross and generation were selected for the single rows in 1986.

Derived Lines

Seed from fifteen randomly selected spikes from the F_2, F_3, F_4 bulked populations and parents during 1984 were sown in single-row plots on May 1, 1985. Only F_3-derived F_5 lines were used for comparisons with means and variances of early generation bulked populations. Cultural practices were similar to other populations. Data on the three traits were recorded on a row basis. In order to produce the F_3 generation for the 1986 crop season, all the crosses were again made in the greenhouse during fall 1985, and the seed produced was replanted to obtain seed of the F_3 generation.

Parents, F_3, F_4, F_5, and F_6 bulked and spaced-planted populations, and head rows were planted at Brookings on May 5, 1986. All other practices followed were the same as in 1985.

Weather Conditions

The growing season in 1985 was characterized by near normal moisture during the early stages of growth (tillering and stem extension), but below normal precipitation during June followed by, to some extent, sufficient moisture during July (Table 3). Unusual weather conditions throughout the 1986 crop season (Table 3), caused nonuniform germination, reduced tillering and plant height, small spikes, and small, unfilled grain. Germination rate for the

Table 3. Monthly mean temperature (C), total precipitation (cm) and departure from normal during crop season 1985 and 1986.

		1985		
	Temperature		Precipitation	
Month	Mean	Departure From Normal	Total	Departure From Normal
April	9.16	2.66	5.10	-0.02
May	15.27	1.93	9.06	1.29
June	16.22	-2.44	2.08	-9.11
July	20.16	-1.34	3.78	-3.45
		1986		
April	7.66	1.16	13.61	5.48
May	13.44	0.10	9.44	1.67
June	19.44	0.76	11.22	0.02
July	21.83	0.31	9.42	2.18

greenhouse produced F_3 generation was so poor that it was not included in the analysis. Continuous rain early in the season not only delayed the planting but also resulted in dense and vigorous weed growth. Temperatures remained close to normal throughout the crop season of 1986 and in the two early months of 1985; however, temperatures dropped 1 to 2 C below normal in June and July of 1985.

Statistical Analysis

Early generation estimates of mean for each cross for the three traits studied were obtained from the mean values of the F_3 and F_4 replicated bulked populations grown in 1985 and 1986, respectively. Variance estimates were obtained from the spaced-planted populations of the same generations planted that year. Means and variances of the head rows of the 15 crosses were used as estimates of mean and variance of the Fn+2 derived lines.

Pearson and Spearman correlations between early generation means and variances and means of the derived lines were used to determine the ability of those early generation parameters to predict crosses giving rise to a high frequency of superior segregates. Early generation means and variances were correlated with the value of the most superior (top-one) and mean of the five most superior (top-five) segregates for each cross in addition to the mean of all derived lines for a cross. A significant, positive correlation signified a parameter as an effective predictor. Pearson correlations for each trait were computed with untransformed data while Spearman correlations were obtained using rankings of the 15 crosses. Correlations were computed for individual years and combined. For the combined analysis trait values were adjusted with the equation:

$$Y_{adj} = Y_{..} + (Y_{unadj} - Y_{.})$$

Where Y_{adj} = Adjusted value

$Y_{..}$ = Grand mean value

Y_{unadj} = Unadjusted value

$Y_{.}$ = Yearly mean value

Analysis of variance was used to determine whether or not the parents differed for the traits under investigation and also to determine the differences among crosses for yield, time to heading, and plant height. The linear additive model used was:

$$Y_{ijk} = u + r_i + g_j + (rg)_{ij} + e_{ijk}$$

Where u = Experimental mean effect

r_i = Effect of the ith cross

g_j = effect of the jth generation

$(rg)_{ij}$ = Interaction effect of the ith cross and jth generation

e_{ijk} = Error effect of the ijkth observation.

To determine the difference among individual parent or cross performance, Fisher-protected LSD values were determined.

RESULTS

Parental Performance

Mean values for yield, time to heading, and plant height are given for bulked and spaced-planted populations and head rows in Tables 4, 5, and 6, respectively. Significant mean differences were found among the parents for yield, time to heading, and plant height in 1985 and for time to heading in 1986 for bulked populations (Table 4).

Grain yield of the parents in bulked and spaced-planted populations ranked differently than the original characterization. In 1985, mean yield of the low-yielding parent, Alex, was statistically similar to the yields of SD2861, Guard, and Protor, the high-yielding parents. In spaced-planted populations all parents, except SD2861, showed similar yields (Table 5). In head rows, however, parents performed as originally characterized (Table 6). In 1986, the high-yielding parent, Protor, performed poorly and was ranked second lowest in both populations and head rows. The other two high-yielding parents, Guard and SD2861, yielded significantly more than the low-yielding parents in the three evaluation methods.

The high-yielding parents headed 2 or 5 days earlier on the average than low-yielding parents in bulked and spaced-planted populations in 1985. In head rows, however, Guard headed in the

Table 4. Parental yield (g), time to heading[a] and plant height (cm) in bulked populations grown in 1985 and 1986 at Brookings.

	Yield		Time to Heading		Plant Height	
Cultivar	1985	1986	1985	1986	1985	1986
SD2861	1881	576	61	51	88	80
Guard	1902	724	62	51	88	78
Protor	1914	508	62	52	84	74
Eureka	1679	463	65	53	106	83
Alex	1897	522	66	51	105	78
Pondera	1737	607	64	52	89	84
LSD 0.05	177	192	0.9	0.9	4.4	8
Prob. of F values	*	0.12	**	**	**	0.18

*, ** Significant at 0.05 and 0.01 probability levels, respectively.

[a] Days to heading after April 19 in 1985 and May 5 in 1986.

Table 5. Parental yields (g), time to heading[a] and plant height (cm) in spaced-planted populations grown in 1985 and 1986 at Brookings.

	Yield		Time to Heading		Plant Height	
Cultivar	1985	1986	1985	1986	1985	1986
SD2861	9	4	62	53	82	67
Guard	7	5	62	53	82	67
Protor	7	3	62	56	76	57
Eureka	7	4	64	54	97	74
Alex	7	4	66	53	95	59
Pondera	7	2	64	55	82	68

[a] Days to heading after April 19 in 1985 and May 5 in 1986.

Table 6. Parental yields (g), time to heading[a] and plant height (cm) in head rows grown in 1985 and 1986 at Brookings.

	Yield		Time to Heading		Plant Height	
Cultivar	1985	1986	1985	1986	1985	1986
SD2861	101	54	60	49	79	74
Guard	108	72	63	48	84	72
Protor	122	28	62	50	86	62
Eureka	95	44	63	52	79	82
Alex	84	35	63	52	76	84
Pondera	91	21	61	53	83	69

[a] Days to heading after May 1 in 1985 and May 5 in 1986.

same number of days as Alex and Eureka; Pondera headed 1 to 2 days earlier. In 1986, two high-yielding parents, SD2861 and Guard, and one low-yielding parent, Alex, headed 1 to 3 days earlier than the other three parents in bulked and spaced-planted populations. For head rows all three high-yielding parents headed 2 to 5 days earlier than the low-yielding parents.

For plant height in 1985, the low-yielding parents Eureka and Alex as expected, were taller in bulked populations (106 and 105 cm, respectively) as compared to SD2861, Guard, and Protor, high-yielding parents (Table 4). Pondera, the third low-yielding parent, was similar in height to the high-yielding parents. A similar trend was observed in spaced-planted populations since Eureka and Alex were taller than the three high-yielding parents, while Pondera was similar to SD2861 and Guard (Table 5). Mostly opposite results, however, were obtained in head rows in 1985. Eureka and Alex were shorter than the high-yielding parents, SD2861, Guard, and Protor, and Pondera was taller than SD2861 but shorter than Guard and Protor (Table 6).

Plant heights in 1986 showed mixed results. Protor, a high-yielding parent, was the shortest among all the parents in bulked and spaced-planted populations, and head rows, while other parents were inconsistent. Pondera was tallest in the bulked and spaced-planted populations with a mean height of 84 cm and 68 cm, respectively, while second to shortest in the head rows. Similarly, Alex had a mean height of 84 cm and was the tallest in head rows and second shortest in bulked and spaced-planted populations with a mean height of 78 cm and 59 cm, respectively.

Performance of Crosses:

Analysis of variance showed significant differences among the crosses for yield, time to heading, and plant height in both years (Table 7). Generations were significantly different only for time to heading in both years. Highly significant interactions between cross and generation was detected for time to heading in both years, and for plant height in 1986. This interaction was not significant for yield in either year or for plant height in 1985.

Mean and variance performances of the 15 crosses in early generation bulked populations and derived lines were evaluated. The results will be presented in the following order; grain yield, time to heading, and plant height.

Yield

In 1985, the four highest-yielding crosses not differing significantly in the bulked F_3 populations were crosses 1, high x high parents, and 5, 7, and 8, high x low parents (Table 8). The mean yield of these crosses was 1866, 1945, 1928, and 1969 grams, respectively. Cross 14, low x low parents, with a mean yield of 1614 grams (16% less than the highest-yielding group) was

Table 7. Analysis of variance for 15 spring wheat crosses in bulked populations in 1985 and 1986.

		1985			1986		
Source	df	Yield	Time to Heading	Plant Height	Yield	Time to Heading	Plant Height
Rep	2	**	*	0.11	0.36	0.37	**
Cross	14	**	**	**	**	**	**
Generation	2	0.80	**	0.33	0.81	**	0.16
Cross x Generation	26	0.27	**	0.59	0.22	**	*
Error	84						

*, ** Significant at 0.05 and 0.01 probability levels, respectively.

the lowest yielding cross and was followed by crosses 6, 9, 10, and 11, all high x low parents. In 1986, cross 10 produced the highest mean yield, 610 grams, from bulked F_4 populations and did not differ significantly from crosses 1, 3, 7, and 8 (Table 9). Cross 14 was again one of the lowest yielding bulked population means with only cross 4 being lower. The yield of cross 4 was 411 grams, 28% less than the high-yielding crosses. Other low-yielding crosses were crosses 5 and 9, high x low parents, and cross 15, low x low parents.

Cross 3, high-yielding parents, exhibited the largest variance (10.53) in F_3 spaced-planted populations in 1985 (Table 8). It was closely followed by crosses 4, 5, and 9, high x low parents, and cross 15, low x low parents. Crosses 14, 10, and 11 with values of 4.33, 4.64, and 4.69, respectively, showed the smallest variances. This situation reversed somewhat in 1986. The poorly performing cross 10 in 1985, showed the largest variance in 1986 with a value of 5.05 and cross 3 displayed a comparatively small variance (2.03) (Table 9). The other three crosses which produced the larger variance values in 1986 were crosses 1, 5, and 6, while crosses 7, 13, and 14 produced the smaller variances.

The relationship between means and variances of the early generation bulked populations produced inconsistent results. Correlation values 0.31 and 0.30 for 1985 and 1986, respectively, were nonsignificant but positive. A number of crosses with higher or lower mean yield did not produce similar results for variances.

Table 8. Yield (g) of F_3-derived F_5 lines and early generation means and variances in 1985.

	F_3[a]		F_3 Derived F_5 Lines			
Cross No.	Mean	Variance	Mean	Range	Top-Five	Top-One
			High x High Crosses			
1	1866	6.25	118	176	180	209
2	1830	5.55	73	85	100	110
3	1813	10.53	143	142	192	225
			High x Low Crosses			
4	1850	8.07	79	118	116	145
5	1945	9.32	87	89	117	128
6	1767	6.58	108	135	152	174
7	1928	5.42	110	148	156	192
8	1969	5.09	63	139	105	149
9	1769	7.73	74	80	102	110
10	1725	4.64	71	139	116	148
11	1752	4.69	101	121	135	143
			Low x Low Crosses			
13	1821	6.16	82	160	131	185
14	1614	4.33	79	106	114	136
15	1834	8.63	95	135	128	145
$LSD_{0.05}$	85					

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[a] Means and variances estimated from bulked and spaced-planted populations, respectively.

Table 9. Yield (g) of F_4-derived F_6 lines and early generation means and variances in 1986.

Cross No.	F_4[a] Mean	F_4[a] Variance	F_4 Derived F_6 Lines Mean	Range	Top-Five	Top-One
			High x High Crosses			
1	563	4.54	77	140	110	162
2	487	3.28	71	122	112	145
3	557	2.03	64	114	104	141
			High x Low Crosses			
4	411	3.36	52	100	87	109
5	452	4.27	44	59	59	72
6	470	4.22	47	70	73	83
7	548	1.39	39	61	61	74
8	557	2.28	39	68	59	73
9	454	1.24	41	97	61	106
10	610	5.05	42	74	66	83
11	418	2.56	42	95	71	109
			Low x Low Crosses			
13	489	0.73	50	100	81	106
14	413	0.63	45	70	64	90
15	442	2.08	32	111	54	121
$LSD_{0.05}$	85					

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[a] Means and variances estimated from bulked and spaced-planted populations, respectively.

Some crosses, however, were equally high or low in means and variances. Examples are crosses 5, 10, 11, and 14 in 1985, and crosses 1, 10, and 14 in 1986 (Tables 8 and 9).

The use of means and variances of the early generations of bulked populations appears to moderately predict those crosses which produced the greater proportion of high-yielding derived lines. Pearson and Spearman correlation coefficients were computed. Yields of F_n bulked populations and F_n spaced-planted variances were correlated with yields of derived lines in the F_{n+2} generation where n = 3 and 4 in 1985 and 1986, respectively. Correlations were made of means yields over all the crosses in 1985 and 1986 and combined over years (Tables 10 and 11). Both Pearson and Spearman correlation coefficients detected a positive relationship for all the comparisons, except for Spearman correlation coefficients between F_4 bulked population means and means of the top-one derived lines in 1986. The two highest correlation coefficients in 1985, 0.44 and 0.32, were obtained with Pearson correlation coefficients when variances of the spaced-planted populations were correlated with the means of all the derived lines and top-five lines, respectively. The lowest correlation values, 0.05 and 0.08, were obtained when early generation bulked means were correlated with the means of the derived lines and top-five lines, respectively. Comparisons of F_3 bulked population means and spaced-planted population variances with the means of the top-one lines gave similar correlation values

Table 10. Pearson correlation coefficients for yield among F_n[a] generation means and variances and F_{n+2} derived lines for 15 crosses of spring wheat in 1985, 1986 and years combined.

		r		
F_n Generation	F_{n+2} Generation	1985	1986	Combined
Mean of Bulked Populations	Top One	0.17	0.08	0.14
	Top Five	0.08	0.21	0.13
	Mean	0.05	0.24	0.11
Variance of Spaced-Planted Populations	Top One	0.20	0.10	0.16
	Top Five	0.32	0.24	0.29
	Mean	0.44	0.30	0.39*

* Significant at 0.05 and 0.01 probability levels, respectively.

[a] n = 3 and 4 in 1985 and 1986, respectively.

Table 11. Spearman correlation coefficients for yield among F_n[a] generation means and variances and F_{n+2} derived lines for 15 crosses of spring wheat in 1985, 1986 and years combined.

F_n Generation	F_{n+2} Generation	r		
		1985	1986	Combined
Mean of Bulked Populations	Top One	0.18	-0.02	0.06
	Top Five	0.07	0.19	0.11
	Mean	0.04	0.06	0.09
Variance of Spaced-Planted Populations	Top One	0.11	0.01	0.06
	Top Five	0.30	0.20	0.26
	Mean	0.39	0.23	0.34

[a] n = 3 and 4 in 1985 and 1986, respectively.

of 0.17 and 0.20, respectively.

In 1986, variances of the spaced-planted populations produced larger coefficient values as compared to means of the bulked populations. Correlation coefficients computed for both years combined were not much different than the individual year comparisons. However, significant and positive correlation coefficients were obtained when variances of spaced-planted populations were correlated with the means of the derived lines. With few exceptions, both Pearson and Spearman correlation coefficients were similar in detecting the different relationships.

Since cultivars of wheat are inbred lines, the mean yields of the derived lines are of interest. In 1985, cross 1 and 3, high x high parents, produced F_5 lines with the maximum mean yield of 118 grams and 143 grams, respectively (Table 8). Cross 1 with a bulked mean yield of 1866 grams, and cross 3, with a comparatively low bulked population yield but high variance (10.53), in the F_3 generation were among the best crosses. In addition, the mean yields of the top-five and top-one derived lines of these crosses were among the highest. However, the range of 176 grams for lines derived from cross 1 was the highest and cross 3 was fourth highest. Other high-yielding derived lines were obtained from crosses 6, 7, and 11, high x low parents. Of these, only cross 7 with a mean yield of 1928 grams in bulked population was included among the previously identified superior crosses. The mean yield of the top-five lines from all three crosses and the performance of the top-one line from crosses 6 and 7 followed a similar pattern. Surprisingly, the derived lines which averaged the lowest yield, 63 grams, was derived from cross 8. This cross had produced the maximum mean yield of 1969 grams in F_3 bulks. The other low-yielding means for derived lines were from crosses 2, 9 and 10. These crosses, with either low means or variances or both, were not included among the best performing crosses. The differences in range for top-five line performances of these crosses were similar to the other crosses (Table 8).

In 1986, the highest-yielding derived lines (means, top-one and top-five) and maximum ranges were obtained from crosses 1, 2, and 3, all with high-yielding parents (Table 9). Among these, cross 1 with the second highest mean (563 grams) and variance (4.54) for yield and cross 3 with a mean yield of 557 grams were considered the best crosses. High yielding derived lines were also obtained from crosses 4 and 13. Cross 4, however, had the lowest bulked population mean yield, 411 grams. Cross 13 with a mean of 489 grams and variance 0.73 for yield also produced some higher-yielding derived lines. The range, top-one, and top-five derived lines obtained for crosses 4 and 13 showed similar values (Table 9). The lowest mean for all the top-five lines and derived lines were obtained from crosses 15, 7 and 8. Based on the performance of bulked populations these crosses should have been among the best crosses for derived lines.

The three bulked population generations were examined to identify which generation was superior in predicting crosses producing high-yielding derived lines. Correlation coefficients between the bulked population means of the F_3, F_4, F_5, and their average combined and F_3 derived F_5 lines (top-one, top-five, means and variances) in 1985 showed nonsignificant but positive relationships for all the comparisons. Means for the bulked populations and derived lines are given in Table 12. Since all the correlations were nonsignificant they will not be presented. Correlation values for F_4, F_5, and average of all the generations combined were higher than F_3. The highest coefficient was 0.07 for the F_4 generation. The lowest was 0.05 for the F_3 generation. The trend of late generations having more predicted value can be seen in Table 12. In the F_4 the four higher performing crosses produced the higher yielding derived lines and was followed by F_5 and average of all the generations combined, in each case the three high-yielding crosses produced the high-yielding derived lines. The F_3 generation was comparatively less efficient. Only two high-yielding crosses produced the high-yielding derived lines.

In 1986, the relationship between the mean yield of derived lines and bulked mean yields of the F_4, F_5, F_6 generations was similar as in 1985 although all correlation coefficients were higher. The highest correlation was between the F_6 bulked population mean and the derived lines was 0.52. The low correlation was 0.25. This was between the F_4 bulked population mean and the mean of the derived line. The bulked mean yields of

Table 12. Yield (g) comparisons among early generation bulked population means with the mean yields of the F_3-derived F_5 lines in 1985.

Cross No.	F_3 Bulk	F_4 Bulk	F_5 Bulk	Average	F_3 Derived F_5 Lines		
					Mean	Top-Five	Top-One
			High x High Crosses				
1	1866	1923	1923	1904	118	180	209
2	1830	1821	1722	1791	73	100	110
3	1813	1718	1784	1772	143	192	225
			High x Low Crosses				
4	1850	1789	1796	1812	79	116	145
5	1945	1828	1724	1832	87	117	128
6	1767	1861	1800	1809	108	152	174
7	1928	1850	1819	1866	110	156	192
8	1969	1965	1956	1963	63	105	149
9	1769	1708	1800	1759	74	102	110
10	1725	1619	1750	1698	71	116	148
11	1752	1846	1876	1824	102	135	143
12	----	1788	1774	----	70	117	151
			Low x Low Crosses				
13	1821	1833	1931	1862	82	131	185
14	1614	----	1671	----	79	114	136
15	1834	1762	1833	1810	95	128	145

$LSD_{0.05}$ for bulked populations is 85 g.

the F_4, F_5, F_6 generations and their means were equally effective in identifying crosses 1, 2, 3, and 13 which produced the derived lines with the highest mean yields of 77, 71, 64, and 50 grams, respectively, as well as the top-one and top-five lines with the highest mean values (Table 13). The other high-yielding derived lines with a mean yield of 52 grams was obtained from cross 4 which was identified as the best cross by F_5, F_6 and the average of all three generations.

Time to Heading

Among the early headed crosses in F_3 bulked populations in 1985, cross 2, high x high parents, and crosses 4 and 5, high x low parents, averaged 60 days to heading (Feeks scale, stage 10.3) and were closely followed by crosses 1 and 3, high x high parents, and 6 and 10, high x low parents, with a mean time to heading of 61 days (Table 14). Crosses 13 and 15, low x low parents, with a mean heading time of 65 days and cross 8, high x low parents, with a heading time of 63 days were the latest among the crosses. In 1986, the earliest-headed crosses were 1, 2, 4, 6, and 10 with a time to heading of 50 days (Table 15). Crosses 8 and 13 were the last to head (54 days).

The largest variance for time to heading in 1985 was 4.67 for cross 13 and was followed by the crosses 9, 14, and 15. Crosses 2 and 6 produced the smallest variance with values 0.24 and

Table 13. Yield (g) comparisons among early generation bulked population means with the mean yields of the F_4-derived F_6 lines in 1986.

Cross No.	F_4 Bulk	F_5 Bulk	F_6 Bulk	Average	F_4 Derived F_6 Lines Mean	Top-Five	Top-One
			High x High Crosses				
1	563	566	591	573	77	109	162
2	487	591	541	540	71	112	145
3	557	553	583	564	64	104	141
			High x Low Crosses				
4	411	587	570	522	52	87	109
5	452	536	486	491	44	59	72
6	470	472	417	453	47	73	83
7	548	372	599	506	39	61	74
8	557	575	573	568	39	59	73
9	454	471	470	465	41	61	106
10	610	437	465	504	42	66	83
11	418	379	441	413	42	71	109
12	---	424	521	---	40	67	90
			Low x Low Crosses				
13	489	570	528	529	50	81	106
14	413	---	388	---	45	64	90
15	442	408	373	408	32	54	121

$LSD_{0.05}$ for bulked populations is 85 g.

Table 14. Time to heading of F_3-derived F_5 lines and early generation means and variances in 1985[a].

	F_3[b]		F_3 Derived F_5 Lines			
Cross No.	Mean	Variance	Mean	Range	Top-Five	Top-One
			High x High Crosses			
1	61	1.22	63	10	61	60
2	60	0.24	62	2	61	61
3	61	1.81	62	5	60	59
			High x Low Crosses			
4	60	1.68	60	2	59	59
5	60	1.22	60	2	60	60
6	61	0.90	61	3	61	60
7	62	1.95	63	5	61	61
8	63	1.56	61	5	59	59
9	62	2.03	62	5	60	60
10	61	1.72	60	2	59	59
11	62	1.49	62	9	60	59
			Low x Low crosses			
13	65	4.67	62	8	60	59
14	62	2.99	62	7	61	59
15	65	2.76	62	6	61	60
LSD	0.4					

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[a] Days to heading after April 19 in bulked and spaced-planted populations and May 1 in derived lines.

[b] Means and variances estimated from bulked and spaced-planted populations, respectively.

Table 15. Time to heading of F_4-derived F_6 lines and early generation means and variances in 1986[a].

	F_4[b]		F_4 Derived F_6 Lines			
Cross No.	Mean	Variance	Mean	Range	Top-Five	Top-One
			High x High Crosses			
1	50	1.74	47	7	45	45
2	50	2.96	48	5	47	46
3	51	2.42	48	5	46	45
			High x Low Crosses			
4	50	5.65	48	8	45	45
5	51	2.73	49	9	46	45
6	50	1.33	48	6	47	46
7	52	5.17	50	7	47	47
8	54	5.59	51	7	49	47
9	52	1.28	50	8	47	45
10	50	4.15	48	10	45	44
11	52	2.41	50	6	47	47
			Low x Low Crosses			
13	54	2.52	53	4	52	51
14	53	1.42	51	5	50	49
15	53	2.81	53	4	52	50
LSD	0.08					

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[a] Days to heading after May 5.
[b] Means and variances estimated from bulked and spaced-planted populations, respectively.

0.90, respectively (Table 14). In 1986, crosses 4, 7, and 8 showed the largest variance with values of 5.65, 5.17, and 5.59, respectively. Crosses 1, 6, 9, and 14 with variance values of 1.74, 1.33, 1.28, and 1.42, respectively, were among the smallest (Table 15).

The comparisons of early generation means and variances of time to heading to the means of lines derived from the bulks are presented in Tables 14 and 15. The F_5 lines which headed 1 to 3 days earlier in 1985 were from crosses 4, 5, and 10. Crosses 4 and 5 were expected to produce early heading lines since they themselves were early heading. Similar response of heading was found in the top-one and top-five lines of these crosses. The lines derived from crosses 1 and 2, early-heading bulked populations, and crosses 13 and 15, late-heading bulked populations, did not follow the pattern of heading of their early generations (Table 14). The lines derived from crosses 1 and 2 headed 2 to 3 days later than those obtained from crosses 13 and 15. This was 3 days earlier than the mean of the lines in early generations. In general, the heading of the top-one and top-five derived lines obtained from both high and low-yielding parents was not in agreement with either F_3 bulked population means or F_5 derived lines.

In 1986, the F_4 derived F_6 lines headed 1 to 6 days earlier than the mean of the other derived lines from crosses 1, 2, and 3, all high-yielding parents. Similar results were seen with crosses

4, 6, and 10, all high x low parents (Table 15). These crosses were early heading in their bulked population performance. Variances, however, were not consistent. The lines derived from the crosses of low by low parents followed a similar pattern of heading to their F_3 bulks for the mean, top-one and top-five lines.

The comparison of the F_n derived F_{n+2} lines with the mean values from early generations bulked populations is given in Tables 16 and 17. The individual F_3, F_4, and F_5 values and their average effectively predicted crosses 4, 5, and 10 as producing lines headed 1 to 4 days earlier than the average of the derived lines (Table 16). The derived lines obtained in the other crosses did not follow their pattern of heading in early generations. Correlations between early generation bulked population means and the means of the derived lines were nonsignificant and in some cases negative.

In 1986, the crosses which were identified as early in heading in F_4, F_5, and F_6 generations and their average, produced lines which were relatively early in heading (Table 17). Similarly, the lines which were late to head were derived from crosses which headed late in all the bulked generations tests.

The Pearson and Spearman correlation coefficients showed positive, significant relationships between F_n bulked means and the means of the F_{n+2} derived, top-one, and top-five lines in 1986 and in both years combined. Variance values were generally not correlated with F_{n+2} derived line values (Tables 18 & 19).

Table 16. Time to heading[a] comparisons among early generation bulked population means with the mean heading of the F_3-derived F_5 lines in 1985.

					F_3 Derived F_5 Lines		
Cross No.	F_3 Bulk	F_4 Bulk	F_5 Bulk	Average	Mean	Top-Five	Top-One
			High x High crosses				
1	61	59	61	60	63	61	60
2	60	61	62	61	62	61	61
3	61	62	61	61	62	60	59
			High x Low Crosses				
4	60	59	61	60	60	59	59
5	60	61	60	60	60	60	60
6	61	62	61	61	61	60	60
7	62	62	63	62	63	61	61
8	63	62	63	63	61	59	59
9	62	62	63	62	62	60	60
10	61	61	61	61	60	59	59
11	62	62	61	63	62	60	59
12	--	61	62	--	64	62	61
			Low x Low Crosses				
13	65	65	65	65	62	60	59
14	62	--	63	--	62	61	59
15	65	65	65	65	62	61	60

$LSD_{0.05}$ for bulked populations if .4 days.

[a] Days to heading after April 19 in bulk and May 1 in derived lines.

Table 17. Time to heading[a] comparisons among early generation bulked population means with the mean heading of the F_4-derived F_6 lines in 1986.

Cross No.	F_4 Bulk	F_5 Bulk	F_6 Bulk	Average	F_4 Derived F_6 Lines		
					Mean	Top-Five	Top-One
			High x High Crosses				
1	50	50	49	50	47	46	45
2	50	52	51	51	48	47	46
3	51	51	52	51	48	46	45
			High x Low Crosses				
4	50	49	50	50	48	45	45
5	51	51	51	51	49	46	45
6	50	51	51	51	48	47	46
7	52	53	52	52	50	47	47
8	54	53	53	53	51	49	47
9	52	51	52	52	50	47	45
10	50	52	51	51	48	45	44
11	52	53	53	53	50	47	47
12	--	55	51	--	50	48	47
			Low x Low Crosses				
13	54	53	54	54	53	52	51
14	53	--	53	--	51	50	49
15	53	54	54	54	53	52	50

$LSD_{0.05}$ for bulked populations is .08 days.

[a] Days to heading after May 5.

Table 18. Pearson correlation coefficients for time to heading among F_n[a] generation means and variances and F_{n+2} derived lines for 15 crosses of spring wheat in 1985, 1986 and years combined.

F_n Generation	F_{n+2} Generation	r 1985	r 1986	r Combined
Mean of	Top One	-0.19	0.69**	0.38*
Bulked	Top Five	0.12	0.73**	0.49**
Populations	Mean	0.25	0.85**	0.58**
Variance of	Top One	-0.42	-0.11	-0.17*
Space-Planted	Top Five	-0.03	-0.14	-0.12*
Populations	Mean	0.02	0.06	0.05*

*, ** Significant at 0.05 and 0.01 probability levels, respectively.

[a] n = 3 and 4 in 1985 and 1986, respectively.

Table 19. Spearman correlation coefficients for heading among F_n[a] generation means and variances and F_{n+2} derived lines for 15 crosses of spring wheat in 1985, 1986 and years combined.

F_n Generation	F_{n+2} Generation	r 1985	 1986	 Combined
Mean of	Top One	-0.20	0.64**	0.27
Bulked	Top Five	0.12	0.74**	0.41*
Populations	Mean	0.30	0.82**	0.54**
Variance of	Top One	-0.34	-0.01	-0.11
Spaced-Planted	Top Five	-0.07	-0.09	-0.05
Populations	Mean	0.05	0.16	0.07

*, ** Significant at 0.05 and 0.01 probability levels, respectively.

[a] n = 3 and 4 in 1985 and 1986, respectively.

Plant Height

In 1985, crosses 2 and 6 showed the shortest F_3 bulked population mean plant heights of 86 and 88 cm, respectively (Table 20). Two other crosses which produced relatively short plants were crosses 1 and 3 with means, of 93 and 94 cm, respectively. Crosses 13 and 15, low-yielding parents, showed the tallest mean plant heights (107 cm) and were followed by the crosses 14 and 5 with the mean heights of 104 cm and 103 cm, respectively. In 1986, crosses 1, 2, 3, and 6 with mean plant heights of 73, 73, 76, and 77 cm, respectively, displayed the shortest bulked means (Table 21). The tallest three crosses with a plant height of 90 cm, were crosses 5, 13 and 14. These were followed by crosses 10, 11, and 15 with statistically similar but shorter plant heights.

Cross 1 displayed the largest variance with a value of 83 for plant height (Table 20). Other crosses with large variances were crosses 5, 10, and 3 with values of 78.98, 63.54, and 60.71, respectively. Crosses 2, 6, 7, and 8 with variance values of 20.87, 26.40, 14.75, and 26.06, respectively, were the smallest. The largest variance values in 1986 were from crosses 5 and 11. Crosses 7, 9, and 10 produced the smallest (Table 21).

Unlike yield and time to heading, means and variances of early generation bulked populations for plant height in 1985 were not consistent in identifying crosses producing the shorter-derived lines (Table 20). Except for cross 2 with the shortest

Table 20. Plant height (cm) of F_3-derived F_5 lines and early generation means and variances in 1985.

	F_3[a]		F_3 Derived F_5 Lines			
Cross No.	Mean	Variance	Mean	Range	Top-Five	Top-One
			High x High Crosses			
1	93	83.00	77	14	72	71
2	86	20.87	70	14	67	60
3	94	60.71	83	14	78	76
			High x Low Crosses			
4	100	48.90	74	12	71	69
5	103	78.98	76	16	71	68
6	88	26.40	79	15	74	72
7	100	14.75	75	14	72	71
8	99	26.06	65	12	61	58
9	98	50.66	72	15	68	63
10	100	63.54	73	10	70	68
11	99	45.45	73	22	66	64
			Low x Low Crosses			
13	107	53.93	69	15	64	61
14	104	51.36	69	25	61	54
15	107	49.02	75	11	72	71
LSD	2.68					

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[a] Means and variances estimated from the bulked and spaced-planted populations, respectively.

Table 21. Plant height (cm) of F_4-derived F_6 lines and early generation means and variances in 1986.

	F_4[a]		F_4 Derived F_6 Lines			
Cross No.	Mean	Variance	Mean	Range	Top-Five	Top-One
			High x High Crosses			
1	73	56.40	81	17	76	71
2	73	54.14	70	28	63	55
3	76	59.79	68	25	59	55
			High x Low Crosses			
4	83	49.07	80	28	71	61
5	90	77.49	81	15	76	73
6	77	56.57	76	25	69	63
7	85	19.35	75	17	70	66
8	84	47.64	74	25	67	61
9	83	36.48	71	25	64	55
10	86	30.41	75	33	67	61
11	86	77.83	75	22	68	63
			Low x Low Crosses			
13	90	43.48	82	33	72	55
14	90	59.48	81	24	76	71
15	86	62.29	83	20	79	76
LSD	5					

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[a] Means and variances estimated from bulked and spaced-planted populations, respectively.

bulked population mean height of 86 cm and derived lines averaging 70 cm neither population parameter effectively identified crosses producing the shorter derived lines. Crosses 13, 14, and 15 showed the tallest F_3 bulked population mean but comparatively short F_5 lines. The top-one and top-five lines for these crosses were mostly in agreement with the F_5 line mean values (Table 20).

In 1986, all the shorter F_6 lines were obtained from crosses 2, 3, 8, 9, and 10 (Table 21). Crosses 2 and 3 would have been identified by their bulked mean values as the crosses likely to produce shorter F_6 lines. Crosses 8, 9, and 10 with bulked mean heights of 84, 83, and 86 cm, respectively, would not have been identified as producing short derived lines. The variance parameter was not effective in identifying the crosses which produced the shorter F_6 derived lines (Table 21).

The means of the early generation bulked populations for plant height and means of the F_n derived F_{n+2} lines are given in Tables 22 & 23. Among the 15 crosses, only crosses 2 and 9 were somewhat consistent in all three generations and F_5 lines in 1985 (Table 22). The other crosses were either inconsistent in their performance in the early generations or inconsistent between plant heights of early generations and derived lines.

The derived lines with short plant heights were obtained from crosses 2, 3, 9, and 12 in 1986 (Table 23). The mean height of the cross 3 was consistently shorter in all three bulked generations (crosses were ranked in each generation separately) and

Table 22. Plant height (cm) comparisons among early generation bulked population means with the mean heights of the F_3-derived F_5 lines in 1985.

Cross No.	F_3 Bulk	F_4 Bulk	F_5 Bulk	Average	F_3 Derived F_5 Lines		
					Mean	Top-Five	Top-One
			High x High Crosses				
1	93	100	98	98	77	72	71
2	86	86	84	85	70	67	60
3	94	92	93	93	83	78	76
			High x Low Crosses				
4	100	107	100	102	74	71	69
5	103	105	102	103	76	71	68
6	88	90	88	89	79	74	72
7	100	100	98	99	75	72	71
8	99	100	99	99	65	61	58
9	98	98	99	98	72	68	63
10	100	97	97	98	73	70	68
11	99	101	96	98	73	66	64
12	--	93	90	--	78	71	69
			Low x Low Crosses				
13	107	106	105	106	69	64	61
14	104	---	106	---	69	61	54
15	107	108	109	108	75	72	71

$LSD_{0.05}$ for bulked populations is 2.68 cm.

Table 23. Plant height (cm) comparisons among early generation bulked population means with the mean height of the F_4-derived F_6 lines in 1986.

					F_4 Derived F_6 Lines		
Cross No.	F_4 Bulk	F_5 Bulk	F_6 Bulk	Average	Mean	Top-Five	Top-One
			High x High Crosses				
1	73	80	85	79	81	76	71
2	73	86	80	80	70	63	55
3	76	79	80	78	68	60	55
			High x Low Crosses				
4	83	91	92	89	80	71	61
5	90	93	90	91	81	76	73
6	77	81	80	80	76	69	63
7	85	77	81	81	75	70	66
8	94	86	86	85	74	68	61
9	83	84	79	82	71	64	55
10	86	80	82	82	75	67	61
11	86	80	83	83	75	68	63
12	--	91	80	--	68	62	58
			Low x Low Crosses				
13	90	94	86	90	82	73	55
14	90	--	84	--	81	76	71
15	86	90	90	88	83	80	76

$LSD_{0.05}$ for bulked populations is 5 cm.

their average combined, whereas cross 2 and 9 were shorter in all generations and their average, except for the F_5. All other crosses did not perform consistently.

In all cases nonsignificant coefficients for Pearson and Spearman correlations were detected in 1985 and 1986, individually and combined over years (Table 24 and 25).

Table 24. Pearson correlation coefficients for plant height among F_n[a] generation means and variances and F_{n+2} derived lines for 15 crosses of spring wheat in 1985, 1986 and years combined.

F_n Generation	F_{n+2} Generation	r		
		1985	1986	Combined
Mean of Bulked Populations	Top One	-0.18	0.27	0.05
	Top Five	-0.31	0.43	0.07
	Mean	-0.29	0.47	0.10
Variance of Spaced-Planted Populations	Top One	0.22	0.36	0.28
	Top Five	0.24	0.26	0.25
	Mean	0.29	0.24	0.26

[a] n = 3 and 4 in 1985 and 1986, respectively.

Table 25. Spearman correlation coefficients for plant height among F_n[a] generation means and variances and F_{n+2} derived lines for 15 crosses of spring wheat in 1985, 1986 and years combined.

		r		
F_n Generation	F_{n+2} Generation	1985	1986	Combined
Mean of Bulked Populations	Top One	-0.22	0.37	0.10
	Top Five	-0.31	0.50	0.13
	Mean	-0.29	0.50	0.14
Variance of Spaced-Planted Populations	Top One	0.14	0.45	0.32
	Top Five	0.21	0.30	0.29
	Mean	0.27	0.28	0.28

[a] n = 3 and 4 in 1985 and 1986, respectively.

DISCUSSION

Parents grown in bulked and spaced-planted populations, and single row plots (head rows) showed yields dissimilar to past results (Tables 4, 5 and 6). The characterization of the six parents was based on yield trials conducted at 8 locations in eastern South Dakota in 1982 and 1983. Mean annual yield of the three high-yielding cultivars was 2.37, and 2.47 Mg ha^{-1}, while that for the three low-yielding cultivars was 2.06, and 2.22 Mg ha^{-1}. These differences were not large, but would be considered typical in adapted cultivars. A possible reason for the fluctuation of parental performances may be genotype x environment interactions. The weather exhibited extreme variations during the 1985 and 1986 crop seasons (Table 3). Genotype x environment interactions are a well-known phenomenon in plant breeding (Allard, 1961). In addition, excessive April moisture resulted in delayed planting of the single row plots in 1985 and all three trials in 1986. Late planting is known to reduced grain yield (Cregan and Busch, 1977).

Means and variances of early generation bulked populations have been advocated as a method of predicting crosses giving rise to a high frequency of transgressive segregates. Cregan and Busch (1977) reported that crosses with greater genetic variance were likely to contribute high-yielding lines. In a theoretical paper, Rosielle (1983) argued that crosses with higher variance values in early generation bulked populations could be used for production of segregates with high-yielding potential. By early elimination of undesirable crosses, time, money, and space can be saved in the breeding program (Harlan et al. 1940 and Immer 1941).

One purpose of this study was to test the reliability of early generation bulked population mean yields and variances as predictors of crosses which would produce high-yielding inbred lines. Correlation coefficients of derived lines with early generation bulks was tested by Harrington (1940), Immer (1941), Busch et al. (1974) and Cregan and Busch (1977). They reported bulks were effective in identifying crosses from which higher yielding lines may be obtained. In this study both Pearson and Spearman correlation coefficients detected a positive relationship for all the comparisons, except for Spearman correlation coefficients between F_4 bulked population means and the mean of the top-one derived lines in 1986. The two highest correlation coefficients recorded were 0.44 and 0.32. These were obtained in 1985 by Pearson correlation coefficients for variance of the spaced-planted populations correlated with the mean of all the derived lines and mean of the top-five lines, respectively. The lowest correlation values, 0.05 and 0.08, were obtained when the mean of the early generation bulked was correlated with the mean of the derived lines and mean of the top-five lines, respectively. Comparisons of the F_3 bulk means and spaced-planted variance with the mean of the top-one lines gave similar correlation values of

0.17 and 0.20, respectively.

In 1986, variances of spaced-planted populations relatively larger correlation values as compared to bulked population means, when correlated with the derived lines (top-one, top-five, and mean). A number of factors could be responsible for the low correlation values in individual years. These are: small sample size, non-replicated data for spaced-planted populations, single plot head row trials, weather fluctuations, and late planting. Variances of the spaced-planted populations, however, were significantly and positively correlated with means of the derived lines when combined over years (Tables 12 and 13). All other comparisons produced similar correlation values as individual years. Generally, correlation coefficients were comparatively higher for comparisons between variances of the spaced-planted populations and means of the derived lines, while lower for the comparisons between the means of the bulked populations and means of the derived lines. With few exceptions, both Pearson and Spearman correlations were similar in detecting relationships.

Results of this study indicated that means and variances of early generation bulked and spaced-planted populations may be useful in identifying those crosses which produce superior derived lines. Three of the five highest-yielding lines in 1985, and four of the five in 1986, were obtained from crosses which showed better mean and variance performances in early generation bulked populations. These results agree with the findings of Smith and

Lambert (1968) in barley, Leffel and Hanson (1961) in soybean, and Harrington (1940), and Cregan and Busch (1977) in wheat.

It should be pointed out, however, that early generation means and variances successfully identified only 30% of the crosses which produced the highest-yielding derived lines (mean, top-one and top-five). There were some crosses which performed well in either mean or variance, or both, but did not produce the highest-yielding derived lines (Table 8 and 9). Determining the efficiency of early generation bulks in predicting those crosses which produced the most high-yielding lines revealed that F_4 and F_5 generations and average of all the generations combined, were mostly effective. Busch et al. (1974) reported that the means of the F_4 and F_5 bulks could be used effectively in predicting which crosses to select for greater proportion of high yielding lines. Hurd (1969) proposed a breeding procedure that involved extensive yield testing beginning in the F_4.

In general, derived lines from crosses among low-yielding parents were found to give low-yielding derived lines when compared to those from crosses with high-yielding parents. Derived lines obtained from the crosses of high x low parents, were intermediate in mean yield. These results are similar to those obtained by Busch et al. (1974) with wheat, and Johnson and Hayes (1940) with maize. The proportion of high-yielding derived lines from crosses with high x low parents were approximately equal to those crosses with high-yielding parents in 1985, while most of the high-yielding derived lines in 1986 came from crosses with high-yielding parents. This deviation may be the result of late planting or poor growing conditions during the 1986 crop season (Table 3). In general, progeny obtained from crosses with high-yielding parents produced the highest mean yielding segregates. These results concur with Busch et al. (1974), and Lonnquist and Lindsey (1964), and Linnquist (1968).

Crosses which involved SD2861 or Guard as one of the parents produced higher mean yields and larger variances in early generation bulked and spaced-planted populations and produced higher-yielding derived lines. As expected, both of these parents had been classified as high-yielding parents.

For time to heading, Pearson and Spearman correlation coefficients indicated strong positive relationships between bulked population means and the derived lines (mean, top-five and top-one) in 1986 and over years combined. Nonsignificant and negative correlations between the variances of the spaced-planted populations and means of the derived lines indicates the ineffectiveness of the variance as a predictor of superior crosses.

Mean values for time to heading of the early generation bulked populations were extremely effective in detecting those crosses which produced the earlier-headed derived lines. This could be due to the trait's heritability, since time to heading is considered highly heritable. Variances, however, with their inconsistent performance were less effective. A surprising trend of time to heading in early generation bulks and derived lines of the high x high and low x low crosses in 1985 may be the result of delayed planting of head rows.

Similar to yield, mean values of time to heading in F_4 and F_5 generation bulked populations and their average were quite successful in identifying the crosses which produced the earlier heading derived lines. Crosses involving SD2861 produced the earliest-headed lines. SD2861 proved to be a desirable parent for crossing because of its ability to produce high-yielding and early-headed progeny.

For plant height, in all cases except for crosses 2 and 8 in 1985 and 2 and 3 in 1986, both means and variances were ineffective in predicting crosses which produced short-statured derived lines (Table 20 and 21). A similar situation was observed in the case of early generation bulked populations which also failed to produce any positive results.

SUMMARY AND CONCLUSIONS

The objectives of this study were to evaluate the use of means and variances of early generation bulked populations in identifying those crosses likely to produce greater-yielding inbred lines and to determine which generation would best identify those crosses.

Five spring wheat cultivars (Guard, Protor, Eureka, Alex and Pondera) and one experimental line, SD2861, were crossed in this study. These parents were chosen for their relative adaptiveness to the production conditions of South Dakota. Traits evaluated in bulked and spaced-planted populations and head rows in this study were: 1) grain yield; 2) time to heading; and, 3) plant height.

Field experiments were conducted in the summer of 1985 and 1986. Bulked and spaced-planted populations in F_3 and F_4 generations and F_3 derived F_5 lines were planted in 1985. In 1986 bulked and spaced-planted F_4 and F_5 generations and F_4 derived F_6 lines were planted. Correlations between the means or variances of the early generations and the means of the derived lines across crosses were used to determine which parameter best predicted the crosses producing superior segregates.

Completion of this study led to the following conclusions:

1. The mean yields of the early generation bulked

and variances of the spaced-planted populations were found to be moderately effective in predicting the crosses which produced higher-yielding segregates.

2. The bulked population mean yields of the F_4 and F_5 generations and average across generations were found most effective in identifying the crosses which produced high-yielding segregates.
3. Crosses with high-yielding parents produced the highest-yielding derived lines, however, the proportion of high-yielding derived lines from high x high and high x low crosses were about the same.
4. Crosses which involved SD2861 or Guard as one of the parents produced higher mean yields and larger variances in early generation bulked and spaced-planted populations, respectively, and produced derived lines with higher mean yields.
5. Mean yields of the early generation bulked and variances of the spaced-planted populations were positively correlated with the mean of the derived lines and mean of the top-one and top-five lines, when computed for 1985, 1986 and over years. All comparisons, except one, were nonsignificant. The variance appear to be a better predictor than

the mean at predicting losses producing high-yielding lines.

6. Mean heading of the early generation bulked populations was found to be effective in predicting crosses which produced early-headed derived lines, while the use of population variances was less effective.
7. Mean values of F_4 and F_5 bulked populations and the average over all generations were effective in identifying crosses which produced early-headed derived lines.
8. A strong relationship was found between the mean time to heading of the early generation bulked populations and the mean of the derived lines (top-one, top-five and mean) in 1986.

   Correlations between the variances of the crosses and the means of the derived lines were mostly nonsignificant and negative.
9. Neither means nor variances of early generations were successful predictors of crosses which produced short-statured derived lines. All correlations were non-significant.

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