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Title: PROGENY TESTS FOR PREDICTING GRAIN YIELD AND SELECTED AGRONOMIC TRAITS IN SINGLE, THREE-WAY AND DOUBLE CROSSES IN WHEAT (*TRITICUM AESTIVUM* L. *EM. THELL*.)

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The major objective of this study was to detect and predict the parental combinations with the greatest potential of producing the highest number of desirable progeny in subsequent generations. Five winter wheat cultivars were crossed in all possible combinations as single, three-way, and double crosses. F_1s, F_2s along with their parents were evaluated at two environmentally diverse sites for the following morphological traits: (1) plant height, (2) tiller number, (3) harvest index, and (4) grain yield.

The following information was obtained: (1) general and specific combining ability for each parent, (2) efficiency of single, three-way, and double crosses in producing usable genetic variability, (3) evaluation of the importance of order in which parents are combined in three-way, or double crosses, (4) correlation between mid-parent value and

F_1, mid-parent value and F_2, F_1 and F_2, and heterosis estimate and F_2 for single crosses, and (5) correlation between actual and predicted performance given by two and three models in three-way and double crosses respectively.

Parents with high general combining ability effects (GCA) tended to produce progenies with high population mean values in single crosses. Multiple cross combinations with the highest total GCA (sum of GCA of all parents involved) gave the highest population mean value for all traits measured.

Progenies from single crosses produced the highest grain yield, while three-way and double crosses were not significantly different for this trait in the F_1 generation when average across two locations. No statistical differences for grain yield were observed in the F_2 for any of the three types of crosses.

Double crosses generated the most genetic variability for grain yield followed by three-way crosses with single crosses generating the least.

The top cross parent in a three-way cross had more influence upon progeny than the parents in the original single cross, especially for the low GCA parents.

Parental order in double crosses was important for plant height, tiller number, harvest index, but was not important for grain yield.

The mid-parent value was very useful in predicting plant height, tiller number, and harvest index in the F_1 and F_2 for single crosses, while the F_1 and heterosis estimates were useful in predicting the resulting F_2 for the same traits.

The methods of predicting yield in production of hybrid corn could be applied to wheat in predicting the performance of three-way and double crosses in all traits measured. For grain yield for double crosses however, only the average yield of four parents involved gave significant correlation coefficients between actual and predicted values.

The use of GCA to predict which parental combinations will yield the most promising segregating populations would make wheat breeding much more efficient in improving complex traits such as grain yield.

Progeny Tests for Predicting Grain Yield and Selected Agronomic Traits in Single, Three-way, and Double Crosses in Wheat (*Triticum aestivum* *L.* *em.* *Thell.*)

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PROGENY TESTS FOR PREDICTING GRAIN YIELD AND SELECTED AGRONOMIC TRAITS IN SINGLE, THREE-WAY, AND DOUBLE CROSSES IN WHEAT (*TRITICUM AESTIVUM L. EM. THELL.*)

INTRODUCTION

Since the so-called "Green Revolution" in wheat and rice, progress in breeding for higher yielding cultivars has been slow with concerns expressed regarding possible yield plateaus being reached. One reason cited is the limited amount of genetic diversity available. Wheat breeders have created additional usable genetic variability by crossing winter with spring types. Rice breeders have been utilizing the indica and japonica type crosses for a similar purpose. The possibility of using hybrids rather than the current conventional pure lines is also being investigated in both cereals.

With more genetic variability available it becomes important to utilize such diversity more efficiently. The question then arises as to the best means of selecting parental combinations, and should attention be given to the order in which the parents are combined in three-way, and double crosses. These questions are pertinent for the development of both pure lines and hybrids.

Ten different parents have the potential of resulting in 45 single crosses, 360 three-way crosses, and 630 double crosses if the reciprocal crosses are assumed to be equivalent. The number of possible cross combinations increases geometrically with the number of parents available. Over 35,000 wheat cultivars are now found in the world collection, thus a vast number of crosses could be made. Wheat breeders then are faced with the following problems: (1) the choice of the best parents for hybridization, (2) the choice of the type of cross, i.e. single, three-way, or double, (3) the choice of the best sequence in which to hybridize parents, and (4) the choice of segregating populations where selection practices will be the most productive. The objectives of this investigation were threefold: first, to evaluate the nature and relative contribution to general and specific combining ability of selected cultivars as a means of selecting parents for hybridization; secondly, to compare the efficiency of single, three-way, and double crosses in yield responses and in generating usable genetic variability, and thirdly, to find an appropriate model to predict the worth of parents in providing the greatest probability to select desirable progeny in subsequent generations.

LITERATURE REVIEW

Combining Ability

Combining ability is the relative capacity of an individual to transmit a desirable characteristic to its progeny (Hayes and Immer, 1942).

The concept and application of combining ability was first employed by corn breeders. It was widely used to test the potential performance of inbred lines. The tested inbred lines were either saved or discarded based on the mean of their respective crosses. Much time and effort was required in making and testing potential parental combinations when the number of lines became large. Jenkins and Bruson (1932) proposed a more efficient method of testing inbred lines. This method was to cross the selected inbred lines with a commercial variety then compare the performance of the progeny of such crosses. Using this method they suggested that it is possible to eliminate 50% of the lines without danger of losing any superior material. Since then the inbred-variety method has been used extensively in corn breeding programs.

Inbred lines are classified as good or poor combiners based on their combining ability. Sprague and Tatum (1942) defined combining ability in terms of general and specific combining ability.

> General combining ability is the average performance of a line in hybrid combinations, and as

> such, general combining ability is recognized as primarily a measure of additive gene action. Specific combining ability describes those instances in which certain hybrid combinations do relatively better or worse than would be expected based on the averaged performance of the lines involved. It is regarded as an estimation of the effects of nonadditive gene action.

Using this concept, Rinkle and Hayes (1964) tested single crosses among 15 unrelated inbred lines and concluded that inbred lines which gave the highest general combining ability estimates tended to produce the highest yielding single crosses.

In self-pollinated species, combining ability was used in breeding programs on soybean by Leffel and Hanson (1961), on wheat by Kronstad and Foote (1964), and by Brown *et al.* (1966) and with barley by Smith and Lambert (1968). Most of these studies have used a diallel crossing system and estimated general and specific combining ability by following Griffing's model of analysis (Griffing, 1956).

In wheat, the general combining ability effects were reported as the main constituent of genetic variation for yield and yield components in diallel crosses of winter wheat (Kronstad and Foote, 1964). Similar results in analogous studies were obtained by Brown *et al.* (1966), Bitzer *et al.* (1967), Gyawali *et al.* (1968) and Bitzer and Fu (1972).

Kronstad and Foote (1964) pointed out that combining ability analysis is useful in selecting parents. Lines with high general combining ability effects would make good parents for hybrid wheat production (Peterson et al., 1969).

Prediction of Progeny Performance

Selected parental lines can be combined in many different ways to produce single, three-way, and double crosses. The number of cross combinations available increases geometrically with the number of parents (p). For single crosses p(p-1)/2 are possible. In contrast p(p-1)(p-2)/2 three-way crosses and p(p-1)(p-2)(p-3)/8 different double crosses can be produced from p lines if reciprocal crosses are assumed to be equivalent (Hayes et al., 1955). The task of the breeder would be almost impossible unless some way could be found to predict the performance of the progeny.

In barley, Grafius et al. (1952) examined the data of Harlan et al. (1940) and suggested that it might be possible to select the high yielding crosses on the basis of the parental yield before any crosses were actually made. Sikka et al. (1959) evaluated the potential of 12 wheat crosses based on parental means and early generation values. They concluded that the parental values could be used with considerable advantage in predicting the performance in subsequent generations for spike number, grain number per spike, spike length, number of spikelets per spike, plant height, and heading date. The probability of obtaining desirable segregates for any of these characteristics could be increased by evaluating the parents and crossing only those showing desirable attributes.

Fowlew et al. (1955) studied 45 crosses of hard red winter wheat and concluded that the parental performance was of no value in predicting yield of subsequent progeny. However, preselection determination made on parental performance reliably predicted plant height, maturity and test weight. Reddy and Liang (1972) estimated plant-to-plant genetic variability of yield in 10 F_2 populations of grain sorghum and found that the higher yielding parents tend to produce greater genetic variability for yield with higher population means in F_2.

Jenkins (1935) presented data on four methods of estimating the yield potential of four inbred lines used in double crosses in corn. These methods were based on the average yield of the inbreds in: (1) the six possible single crosses, (2) the four single crosses not used in making the double cross, (3) all possible combinations with ten other inbreds, and (4) top crosses. The correlation coefficients between actual and predicted yield of 42 double crosses using these four methods were 0.75, 0.76 0.73, and 0.61 respectively. As a consequence of this and other research, it had become an accepted practice to predict yield of a double cross from the yield of single crosses not used in the double cross.

Patanothai and Atkin (1974) compared five methods of predicting grain yield of three-way crosses in grain sorghum. They found that the average yield in the two single crosses not used in making three-way crosses ((AxB)x C = 1/2(AxC) + 1/2(BxC)), which was analgous to Jenkin's method two for predicting yield of double crosses in corn, provided a meaningful estimate and seemed preferable to the other methods because of its simplicity and suitability for use with any set of crosses.

In general three-way crosses are designated as (AxB) x C where A and B are the parents used in making the single cross, while C is the parent used to cross with the resulting F_1. Harrington (1952), and Potocanac et al. (1968) found that the parent C, due to the 50% contribution of its germplasm in the resulting progeny, has a much stronger influence upon the progeny than either parent A or B. Therefore the choice of parent C is very critical for success in using three-way crosses.

Potocanac and Engelman (1968) compared single and three-way crosses using five varieties of wheat. They concluded that the three-way crosses in relation to the single crosses gave a wider range and higher percentage of genotypes in the populations for short straw, high fertility per spike and resistance to stem rust.

Experiments with grain sorghum have provided data on the relative performance of single and three-way crosses for yield and other plant characteristics (Jowell, 1972; Otasuka *et al.*, 1972; and Patanothai *et al.*, 1974). Mean grain yield resulting from the two types of crosses did not differ significantly but greater yield stability over a range of environments was indicated for three-way hybrids. Variability among plants for plant height and days to mid-bloom was significantly greater in three-way than within single cross hybrids in the studies by Walsh and Atkin (1973). The variability in maturity within three-way crosses did not seem large enough to cause a problem at harvest. Stephens and Lahr (1973) also concluded that single and three-way crosses did not differ markedly in plant height or maturity.

The studies of Eckhardt and Bryan (1940) showed that the combination with the highest yield in double crosses of corn is likely to be between two single crosses, each derived from different varieties. They also reported that the combination of early/early//late/late was more uniform in maturity where two early and two late lines were combined. In the production of double cross varieties in corn, it is advisable to combine the similar or closely related inbreds in single crosses, and the different or distantly related inbreds in double crosses (Briggs and Knowles, 1966).

Experiments conducted by Richey *et al*. (1934), indicated that about 15% reduction of yield can be expected from planting second generation double crossed seed in corn. Neal (1935) found 26% reduction from planting the F_2 of double crosses and 36% and 48% reduction from planting second generation three-way and single cross corn seed, respectively.

The literature review concerning the evaluation of parents and prediction of the performance of resulting crosses indicated that such practices are well established and have been practiced successfully for many years in cross pollinating species. However, little or no information is available with regard to self pollinating species. Since inbred lines of corn represent homozygous types similar to self pollinating species, concepts employed in the development of hybrid corn might prove successful in the development of either hybrid or conventional cultivars of normally self-pollinated crop species.

MATERIALS AND METHODS

Five genetically diverse winter wheat cultivars were used in this study. These included: 1) 'Yamhill', a mid-tall cultivar developed from the cross 'Heines VII'/'Alba' ('Redmond'), 2) 'Stephens', a semi-dwarf cultivar resulting from the cross of 'Nord Desprez' and Pullman Selection 101, 3) 'Daws', a semi-dwarf cultivar originating from the cross CI 1484//CI 13645/PI 178383, 4) 'Maris Hobbit', a short cultivar developed in England from the cross 'Professeur Marchal'//('Marene Desprez'/V.G. 9114)//TJB 16, and 5) 'Druchamp', a mid-tall cultivar developed in France from the cross 'Vilmorin 27'/'Fleche d' Or'. These cultivars are well adapted to the Pacific Northwest and are resistant to the major disease complexes. They are being used extensively in the breeding programs in the region.

This study was conducted during the 1977-1978 and 1978-1979 growing seasons. In the spring of 1977 all ten possible single crosses were made with the five parents at Hyslop Agronomy Farm near Corvallis, Oregon. The resulting F_1 seed was germinated and vernalized in the growth chamber prior to transplanting into the greenhouse during the winter of 1977 for further hybridizing. Thirty possible three-way crosses and fifteen possible double crosses were made. Approximately two hundred seeds from each cross were obtained. Fifty hybrid seeds per cross were chosen at random, germinated, vernalized, and transplanted into the field at the Horticulture Experimental Station near Corvallis in the spring of 1978. F_2 seeds from the three-way, and double crosses were thus generated through natural selfing. Additional F_1 seeds of single, three-way, and double crosses were made in the spring of 1978 at the Hyslop location. Approximately two hundred and fifty seeds were obtained for each cross.

One hundred and fifteen entries which comprised the five parents, ten F_1s, ten F_2s from single crosses, 30 F_1s, 30 F_2s from three-way crosses and 15 F_1s, 15 F_2s from double crosses were planted at two locations. These sites were on the Hyslop Agronomy Farm and near Pendleton in Eastern Oregon in the fall of 1978.

The two experimental sites represented two widely different environments. The soil type at the Hyslop location is a Woodburn silt loam. A winter rainfall pattern provides a wet environment throughout most of the growing season. Total amount of rainfall during the 1978-1979 season was 857.50 mm. The minimum temperature during the winter was -3.5 C, with a maximum summer temperature of 27.7 C. At the Pendleton location the soil type is a Walla Walla silt loam. A winter rainfall pattern prevails at this site with a total amount of rainfall being 393.95 mm during this investigation. The minimum winter temperature was -14.22 C with a maximum summer temperature of 31.95 C.

Fertilizer application at Hyslop prior to seeding included 33.60 kg of nitrogen, 56.00 kg of phosphorous, and 39.20 kg of sulfur per hectare. A single application of 112.00 kg of nitrogen per hectare was applied as a top dressing in the spring. At the Pendleton location, 156.00 kg per hectare of nitrogen was applied before planting.

The experimental design was a randomized complete block with two replications at each location. The materials were spaced planted in rows three meters long with the plants spaced 30 cm between and within rows. The population size was 20 plants per entry for parents and F_1s of single crosses, 50 plants for F_2s of single crosses, and F_1s and F_2s of three-way and double crosses. Border rows and missing hills were planted to barley to eliminate border effects.

Data were collected from individual plants for plant height, tiller number, harvest index, and grain yield. Plant height was measured in centimeters from the crown to the tip of the tallest culm, excluding awns at maturity. Tiller number was recorded by counting the number of spike-bearing tillers prior to harvest. Harvest index was calculated by dividing the grain weight by the grain and straw weight at harvest. Grain yield was obtained from the clean, dry grain and recorded in grams.

Data obtained from Hyslop and Pendleton were analyzed both separately and together. The following analyses were performed separately:

1. Analysis of variances: to determine if there were significant differences among parents, crosses, and generations for plant height, tiller number, harvest index, and grain yield.
2. Combining ability analysis: the data of F_1s from single crosses were subjected to the Model I method 4 proposed by Griffing (1956) to estimate general and specific combining ability. Model I, a fixed model, was used because the parents constituted a selected group of cultivars. General combining ability is interpreted as the relative performance due primarily to the additive effects of polygenes. Specific combining ability reflects the relative performance due primarily to deviation from the additive scheme.

   Due to the unequal number of plants in the F_1 for single crosses at Pendleton, the analysis of combining ability at this location was omitted.
3. Mid-parent values, $(P_1 + P_2)/2$ and heterosis, $F_1 - (P_1 + P_2)/2$ for each single cross were calculated.
4. Correlation coefficients between mid-parent and F_1, mid-parent and F_2, F_1 and F_2, and heterosis estimate and F_2 were computed for single crosses.
5. Predicting the performance of three-way crosses involved two models:

$$\text{Model I } (A \times B) \times C = 1/4(A + B) + 1/2\ C.$$

Model II (A x B) x C = 1/2(A x C) + 1/2(B x C). The correlation coefficients between actual and predicted performance for all traits under this study were determined.

6. Predicting the performance of double crosses consisted of three models: (1) Model I, the mean performance of six possible single crosses among a set of four lines, (2) Model II, the average performance of four non-parental single crosses, and (3) Model 3, the average performance of the four lines involved. The correlation coefficients between actual and predicted performance were also computed.

The combined data from two locations were subjected to a 3-way analysis of variance to remove possible genotype x environment interaction effects. Phenotypic variances among progenies in the segregating generations of all crosses were computed by pooling variances among plants within each plot of the same generation of each cross. Environmental variances were estimated by the average of variances obtained from nonsegregating parents and F_1s of single crosses. The genetic variances generated by each cross were estimated by subtracting the genotype x environment interaction variances and the environmental variances from the phenotypic variances.

EXPERIMENTAL RESULTS

Hyslop Location

Evaluation of Parents

Observed mean squares for plant height, tiller number, harvest index, and grain yield are given in Table 1. Among 115 genotypes which were comprised of five parents, ten F_1s and ten F_2s for single crosses, 30 F_1s and 30 F_2s for three-way crosses, and 15 F_1s and 15 F_2s for double crosses the differences were highly significant for all traits under investigation. Coefficient of variations are low, 7.09% for plant height, 8.41% for tiller number, 4.73% and 8.29% for havest index and grain yield, respectively.

The observed mean squares from the analysis of variances within parents (Table 2) reveals that the five parents used in this study were not significantly different for harvest index and grain yield. They were, however, significantly different in plant height and tiller number. A comparison of the parent performance is presented in Table 3. Based on Duncan's New-Multiple Range Test (Steel and Torrie, 1960), Yamhill, Stephens, and Daws were not statistically different in plant height. Maris Hobbit was the shortest parent (80.93 cm) being significantly different from the other parents with the exception of Daws. Druchamp was the tallest parent (112.58 cm) and was significantly different from the other parents. Daws was the highest

Table 1. Observed mean squares for plant height, tiller number, harvest index, and grain yield for parents, F_1s, and F_2s of single, three-way, and double crosses grown at the Hyslop location.

		Mean Squares			
Source	D.F.	Plant height	Tiller number	Harvest index	Grain yield
Replication	1	72.03	.57	.00088	610.11
Genotypes	114	93.57**	4.44**	.00086**	45.44**
Error	114	6.15	1.92	.00014	19.22
C.V.		7.09%	8.41%	4.73%	8.29%

**Significant at one percent probability level.

Table 2. Observed mean squares for plant height, tiller number, harvest index, and grain yield for five parents grown at the Hyslop location.

		Mean Squares			
Source	D.F.	Plant height	Tiller number	Harvest index	Grain yield
Replication	1	33.66	2.48	.000160	.00036
Genotypes	4	253.44**	13.48**	.003035	38.04
Error	4	1.24	2.85	.000635	12.58

**Significant at one percent probability level.

Table 3. Comparison of the performance of five parents for plant height, tiller number, harvest index, and grain yield grown at the Hyslop location.

Parents	Means			
	Plant height (cm)	Tiller number	Harvest index	Grain yield (gm/plant)
1. Yamhill	95.65^{bc*}	19.09^{a}	.46	71.52
2. Stephens	95.34^{bc}	20.66^{a}	.48	67.88
3. Daws	86.40^{ab}	25.36^{b}	.48	76.99
4. Maris Hobbit	80.93^{a}	19.69^{a}	.50	71.24
5. Druchamp	112.58^{d}	23.00^{ab}	.40	65.44

*Means without and/or with letter in common are not significantly different based on Duncan's New-Multiple Range Test at five percent probability level.

tillering parent being significantly different from three of the other four parents. Druchamp was an intermediate tillering parent and not significantly different compared to the other cultivars.

Table 4 shows the mean values of F_1s for ten single cross combinations resulting from the crosses of five parents for the four measured characters. The mean squares from the analysis of variances within F_1s are provided in Table 5. Plant height and harvest index were significantly different while no significant differences were observed for tiller number and grain yield.

Analysis of both general and specific combining ability (GCA and SCA respectively) for plant height, tiller number, harvest index, and grain yield is presented in Table 6. For plant height and harvest index the expected mean squares for GCA and SCA were significant. Only GCA was significant for tiller number. Neither GCA nor SCA were found significant for grain yield.

The estimation of GCA effects contributed by each parent are given in Table 7. Druchamp had the highest, while Maris Hobbit had the lowest GCA for plant height. Stephens and Daws both had positive GCA, while the other three parents had negative GCA for tiller number but only the GCA of Stephens was significantly different from Yamhill and Maris Hobbit. For harvest index Maris Hobbit had the largest GCA, while Druchamp had the lowest. There was no

Table 4. Means for plant height, tiller number, harvest index, and grain yield for F_1s of single crosses grown at the Hyslop location.

Crosses	Plant height (cm)	Tiller number	Harvest Index	Grain yield (gm/plant)
	Characteristics			
Yamhill/Stephens	103.70	22.95	.48	77.20
Yamhill/Daws	110.35	20.92	.48	80.70
Yamhill/Maris Hobbit	91.70	19.30	.52	76.90
Yamhill/Druchamp	113.30	19.90	.42	69.90
Stephens/Daws	92.80	23.30	.49	74.15
Stephens/Maris Hobbit	88.45	21.70	.51	81.20
Stephens/Druchamp	112.80	21.65	.46	75.75
Daws/Maris Hobbit	90.90	21.25	.53	81.40
Daws/Druchamp	114.70	22.35	.45	77.30
Maris Hobbit/ Druchamp	102.20	20.90	.48	78.90

The values were the average of ten plants chosen at random.

Table 5. Observed mean squares for plant height, tiller number, harvest index, and grain yield for F_1s of single crosses grown at the Hyslop location.

Source	D.F.	Mean Squares			
		Plant height	Tiller number	Harvest index	Grain yield
Crosses	9	2168.30**	31.55	0.0212**	265.50
Replication	1	283.22	174.85	0.0015	5080.32
Rep. x Crosses	9	55.72	66.39	0.0017	265.50
Error	180	15.85	22.66	0.0006	294.37

**Significant at one percent probability level.

Table 6. Observed mean squares for general combining ability (GCA) and specific combining ability (SCA) from the combining ability analysis for plant height, tiller number, harvest index, and grain yield for F_1 of single crosses grown at the Hyslop location.

		Mean Squares			
Source	D.F.	Plant height	Tiller number	Harvest index	Grain Yield
G.C.A.	4	221.64**	2.82*	0.0022**	15.70
S.C.A.	5	17.18**	.58	0.00013**	9.24
Error	180	0.79	1.13	0.000029	14.72

*Significant at five percent probability level.

**Significant at one percent probability level.

Table 7. Estimates of general combining ability effects for plant height (${}_1\hat{g}_i$), tiller number (${}_2\hat{g}_i$), harvest index (${}_3\hat{g}_i$), and grain yield (${}_4\hat{g}_i$) for five parents grown at the Hyslop location.

Parents	General Combining Ability Effects			
	${}_1\hat{g}_i$	${}_2\hat{g}_i$	${}_3\hat{g}_i$	${}_4\hat{g}_i$
Yamhill	3.56	-0.87	-0.0095	-1.63
Stephens	-3.54	1.30	0.0035	-0.30
Daws	0.13	0.72	0.0082	1.45
Maris Hobbit	-11.70	-0.85	0.0362	3.07
Druchamp	11.55	-0.30	-0.0384	-2.58
S.E. ($\hat{g}_1 - \hat{g}_j$)	0.72	0.87	0.0044	3.13

significant difference between Stephens and Daws; however, they had a larger GCA than Yamhill for this trait. No significant difference was found for GCA between any of the parents for grain yield.

The estimation of SCA for each cross is given in Table 8. The crosses Yamhill/Daws and Stephens/Druchamp had significantly greater SCA for plant height than other crosses, while the cross, Stephens/Daws, had the lowest SCA for this trait. No significant difference in SCA for any of the crosses was found for tiller number or grain yield. Yamhill/Maris Hobbit and Stephens/Druchamp had significantly higher SCA for harvest index than other crosses, while Stephens/Maris Hobbit had the lowest SCA.

Comparison of Yield Responses

Observed mean squares from a functional analysis of variance are presented in Table 9. Among seven groups of genotypes: (1) parents, (2) F_1 of single crosses, (3) F_2 of single crosses, (4) F_1 of three-way crosses, (5) F_2 of three-way crosses, (6) F_1 of double crosses, and (7) F_2 of double crosses, significant differences were found only for grain yield. All traits under this investigation were found to be significantly different for within group source of variation. Table 10 shows the average performance of single, three-way, and double crosses in terms of grain yield. For the F_1 generation the average grain yield of single crosses

Table 8. Estimates of specific combining ability constant ($\hat{s}_{ij}$) for plant height, tiller number, harvest index, and grain yield for ten single crosses grown at the Hyslop location.

Parent	Trait	Parent: Stephens	Daws	Maris Hobbit	Druchamp
Yamhill	Plant height	1.58	4.57	-2.25	-3.90
	Tiller number	1.09	-0.32	-0.41	-0.36
	Harvest index	0.0014	-0.0023	0.0117	-0.0107
	Grain yield	1.83	3.58	-1.84	-3.59
Stephens	Plant height		-5.88	1.60	2.70
	Tiller number		-0.14	-0.17	-0.77
	Harvest index		-0.0017	-0.153	0.0123
	Grain yield		-4.30	1.13	1.33
Daws	Plant height			0.39	0.93
	Tiller number			-0.04	0.51
	Harvest index			0.003	-0.0023
	Grain yield			-0.042	1.13
Maris Hobbit	Plant height				0.27
	Tiller number				0.62
	Harvest index				0.0007
	Grain yield				1.11

Standard Error	Plant height	Tiller number	Harvest index	Grain yield	Limitation
S.E. ($\hat{s}_{ij} - \hat{s}_{ik}$)	1.05	1.51	0.00004	19.63	$i \neq j,k; j \neq k$
S.E. ($\hat{s}_{ij} - \hat{s}_{kl}$)	.52	.75	0.00002	9.81	$i \neq j,k; j \neq k,l; k \neq l$

Table 9. Observed mean squares from randomized complete block functional type of analysis of variance for plant height, tiller number, harvest index, and grain yield for parents, F_1, and F_2 of single, three-way, and double crosses grown at the Hyslop location.

Source	D.F.	Mean Squares: Plant height	Tiller number	Harvest index	Grain yield
Replication	1	72.03	0.57	0.00088	610.11
Genotypes	114	93.57**	4.44**	0.00086	45.44**
Among Groups	6	94.94	7.46	0.00150	398.01**
Within Group[1]	108	93.49**	4.16**	0.00078*	25.85**
W/n parents (G_1)	4	253.44**	13.48**	0.00303	38.04
W/n F_1S.C. (G_2)	9	205.03**	3.55	0.00190	38.01
W/n F_2S.C. (G_3)	9	125.83**	9.96	0.00120**	31.99
W/n $F_1$3-W. (G_4)	29	89.94**	4.04	0.00080**	35.16**
W/n $F_2$3-W. (G_5)	29	81.86**	3.04*	0.00050**	18.94
W/n F_1 D.C.(G_6)	14	43.91**	2.45	0.00020**	19.84
W/n F_2 D.C.(G_7)	14	36.35**	3.18*	0.00027**	11.66
Rep. x Genotypes[2]	114	6.15	1.92	0.00014	19.22
Rep. x Groups	6	9.12	5.00	0.00015	55.45
Rep. x Group 1[3]	4	1.24	2.85	0.00063	12.58
Rep. x Group 2[4]	9	3.88	2.31	0.00011	58.04
Rep. x Group 3[5]	9	8.53	3.89	0.00005	22.36
Rep. x Group 4[6]	29	4.05	1.75	0.00014	13.37
Rep. x Group 5[7]	29	7.95	1.32	0.00002	10.43
Rep. x Group 6[8]	14	5.23	1.17	0.00001	18.67
Rep. x Group 7[9]	14	7.75	1.16	0.00005	9.49

*Significant at five percent probability level.

**Significant at one percent probability level.

[1]Error term for Among Groups.

[2]Error term for Replication, Genotypes, and W/n Groups.

[3,4,5,6,7,8 and 9]Error terms for W/n Groups 1,2,3,4,5,6, and 7 respectively.

Table 10. Comparison of the average grain yield (gm/plant) for single, three-way, and double crosses grown at the Hyslop location.

Generation	Single cross	Three-way cross	Double cross	Difference[1] required for significance
F_1	76.77	72.26	76.08	3.90
F_2	70.14	67.56	67.70	ns
Difference required for significance	3.21	1.84	3.41	

[1]Based on the contrasts.

ns = No comparison due to nonsignificant difference.

and double crosses were not statistically different, however, they were significantly higher than grain yield of three-way crosses. The three types of crosses were not significantly different for grain yield in F_2.

The remaining results from Hyslop location will be presented for single, three-way, and double crosses separately.

Actual and Predicted Performance of Single Crosses

Both within F_1 and F_2 populations of single crosses a significant difference for plant height was found, while no significant differences were found for tiller number and grain yield. Harvest index was significantly different only in F_2 (Table 9).

The comparison of the values for the traits measured involving parents, mid-parent, F_1s, heterosis, and F_2s of single crosses are provided in Table 11. For plant height, the progenies of the crosses Yamhill/Druchamp, Stephens/ Druchamp and Daws/Druchamp were the tallest in F_1. Yamhill/ Daws, and Maris Hobbit/Druchamp were intermediate with Yamhill/Maris Hobbit representing the shortest population in F_1. Similar results were found in F_2 except for the progenies of Daws/Druchamp and Stephens/Maris Hobbit were the tallest and the shortest populations, respectively. No significant difference was found both within F_1 and F_2 populations of single crosses for tiller number, harvest index, and grain yield (Table 9). For harvest index the significant

Table 11. Comparison of the performance, mid-parent, and heterosis values for plant height, tiller number, harvest index and grain yield of single crosses grown at the Hyslop location.

Performance and Value of	Characteristics: Plant height (cm)	Tiller number	Harvest index	Grain yield (gm/plant)
Yamhill	95.65	19.09	.46	71.52
Stephens	95.34	20.66	.48	67.88
mid-parent	95.49	19.87	.47	69.70
Yamhill/Stephens F_1	103.50	21.28	.48	74.89
Heterosis	103.38%	107.09%	102.12%	107.44%
Yamhill/Stephens F_2	97.03	22.12	.46	67.48
Yamhill	95.65	19.09	.46	71.52
Daws	86.40	25.36	.48	76.99
Mid-parent	91.02	22.22	.47	74.25
Yamhill/Daws F_1	101.42	20.73	.48	81.22
Heterosis	121.13%	93.29%	102.12%	109.38%
Yamhill/Daws F_2	105.59	19.58	.47	69.43
Yamhill	95.65	19.09	.46	71.52
Maris Hobbit	80.93	19.69	.50	71.24
Mid-parent	88.29	19.39	.48	71.38
Yamhill/ Maris Hobbit F_1	92.56	18.77	.51	76.29
Heterosis	104.84%	96.80%	106.25%	106.88%
Yamhill/ Maris Hobbit F_2	93.93	19.73	.49	72.51
Yamhill	95.65	19.09	.46	71.52
Druchamp	112.58	23.00	.40	65.44
Mid-parent	104.12	21.04	.43	68.48
Yamhill/Druchamp F_1	112.11	19.00	.43	67.83
Heterosis	107.67%	90.30%	100.00%	99.05%
Yamhill/Druchamp F_2	106.72	18.99	.43	62.01

Table 11 (continued)

Performance and Value of	Characteristics			
	Plant height (cm)	Tiller number	Harvest index	Grain yield (gm/plant)
Stephens	95.34	20.66	.48	67.88
Daws	86.40	25.36	.48	76.99
Mid-parent	90.87	23.01	.48	72.43
Stephens/Daws F_1	92.82	23.27	.50	74.18
Heterosis	102.14%	101.12%	104.42%	102.76%
Stephens/Daws F_2	98.08	22.72	.48	74.03
Stephens	95.34	20.66	.48	67.88
Maris Hobbit	80.93	19.69	.50	71.24
Mid-parent	88.13	20.17	.49	69.80
Stephens/ Maris Hobbit F_1	88.44	21.76	.51	82.51
Heterosis	100.35%	107.88%	104.08%	118.21%
Stephens/ Maris Hobbit F_2	86.51	18.99	.49	67.16
Stephens	95.34	20.66	.48	67.88
Druchamp	112.58	23.00	.40	65.44
Mid-parent	103.96	21.83	.44	66.66
Stephens/Druchamp F_1	112.74	21.66	.45	76.76
Heterosis	108.44%	99.22%	102.27%	115.15%
Stephens/Druchamp F_2	105.05	20.09	.45	68.48
Daws	86.40	25.36	.48	76.99
Maris Hobbit	80.93	19.69	.50	71.24
Mid-parent	83.66	22.52	.49	74.15
Daws/Maris Hobbit F_1	91.01	21.56	.52	79.32
Heterosis	108.78%	95.74%	106.12%	106.97%
Daws/Maris Hobbit F_2	88.25	23.59	.50	73.88

Table 11 (continued)

Performance and Value of	Characteristics			
	Plant height (cm)	Tiller number	Harvest index	Grain yield (gm/plant)
Daws	86.40	25.36	.48	76.99
Druchamp	112.58	23.00	.40	65.44
Mid-parent	99.49	24.18	.44	71.21
Daws/Druchamp F_1	114.37	21.38	.45	74.25
Heterosis	114.96%	88.42%	102.27%	104.26%
Daws/Druchamp F_2	110.01	25.48	.43	74.80
Maris Hobbit	80.03	19.69	.50	71.24
Druchamp	112.58	25.36	.48	76.99
Mid-parent	96.75	21.34	.45	68.34
Maris Hobbit/ Druchamp F_1	101.11	20.92	.47	80.50
Heterosis	104.50%	98.03%	104.44%	117.79%
Maris Hobbit/ Druchamp F_2	97.04	19.81	.46	71.63
Mean of F_1	101.01	21.03	.480	76.77
Mean of F_2	98.82	21.11	.466	70.14
Difference required for significance:				
- Parents	3.09	4.69	ns	ns
- F_1	4.46	ns	ns	ns
- F_2	6.60	ns	.016	ns
- Mean of F_1 and F_2	ns	ns	ns	3.21

ns = No comparison due to nonsignificant difference.

differences were evident only within F_2. The progenies of the crosses Daws/Maris Hobbit, Stephens/Maris Hobbit, Stephens/Daws and Yamhill/Maris Hobbit had a high harvest index and did not differ significantly from each other. Progenies of the crosses Yamhill/Druchamp, and Daws/Druchamp had the lowest harvest index (.43). Progenies of the crosses Yamhill/Daws, Yamhill/Stephens, Maris Hobbit/ Druchamp, and Stephens/Druchamp had intermediate harvest index values.

F_1s on the average were not significantly different from F_2s for plant height, tiller number, and harvest index. However, the F_1 gave significantly higher grain yield than the F_2 (Table 11).

Correlation coefficients between mid-parent values and F_1, mid-parent values and F_2, F_1 and F_2, and heterosis estimates and F_2, for plant height, tiller number, harvest index, and grain yield, are given in Table 12. For plant height, all correlation coefficients were high and significant (.84 for between mid-parent and F_1; .78 for between mid-parent and F_2, .89 for between F_1 and F_2, and .64 for between heterosis and F_2). The correlation between mid-parent and F_2 was the only relationship which was significant for tiller number (.68). All correlation coefficients for harvest index were high and significant ranging from .98 for mid-parent and F_1, to .84 for heterosis and F_2. It can be noted that mid-parent values can be applied to predict the

Table 12. Correlation coefficient between mid-parent and F_1, mid-parent and F_2, F_1 and F_2, and heterosis and F_2 for plant height, tiller number, harvest index, and grain yield, of single crosses grown at the Hyslop location.

Correlation coefficient between	n	Plant height	Tiller number	Harvest index	Grain yield
Mid-parent and F_1	10	+0.84**	+0.52	+0.98**	+0.27
Mid-parent and F_2	10	+0.78**	+0.68**	+0.92**	+0.53
F_1 and F_2	10	+0.89**	+0.47	+0.97**	+0.32
Heterosis and F_2	10	+0.64*	-0.24	+0.84**	+0.005

* Significant at five percent probability level.

**Significant at one percent probability level.

performance of the F_1 and F_2 for plant height as well as harvest index, while the F_1 and heterosis estimate can be used to predict the performance of F_2 with satisfactory results for these traits.

No significantly high correlation coefficient was found for grain yield.

Actual and Predicted Performance of Three-way Crosses

Observed mean squares of within F_1 were significant for all traits with the exception of tiller number. All traits with the exception of grain yield were significant within the F_2 of three-way crosses (Table 9).

The performance of F_1 and F_2 of 30 three-way crosses generated from five parents for plant height, tiller number, harvest index, and grain yield are shown in Table 13 and Table 14 respectively.

Progenies of the crosses Yamhill/Druchamp//Daws were the tallest (110.15 cm) in F_1, while Yamhill/Stephens// Druchamp were the tallest (110.15 cm) in F_2. Progenies of the crosses Yamhill/Stephens//Maris Hobbit were the shortest in both generations (89.18 cm for F_1 and 86.17 cm for F_2).

No significant difference for tiller number was found in F_1; however, significant differences were observed in F_2 populations. Progenies of the cross Stephens/Maris Hobbit// Daws had the highest tiller number (23.67), while Daws/Maris Hobbit//Yamhill had the lowest tiller number (18.50) in F_2.

Table 13. Performance of F_1s for plant height, tiller number, harvest index, and grain yield of three-way crosses grown at the Hyslop location.

Crosses	Plant height (cm)	Tiller number	Harvest index	Grain yield (gm/plant)
Yamhill/Stephens//Daws	102.67	19.85	.47	66.54
Yamhill/Stephens//Maris Hobbit	89.18	18.82	.47	66.76
Yamhill/Stephens//Druchamp	109.78	17.70	.44	62.49
Yamhill/Daws//Stephens	100.68	20.98	.47	70.53
Yamhill/Daws//Maris Hobbit	91.98	20.05	.48	71.44
Yamhill/Daws//Druchamp	109.02	20.58	.43	66.24
Yamhill/Maris Hobbit//Stephens	99.44	20.98	.50	76.78
Yamhill/Maris Hobbit//Daws	100.25	20.87	.49	77.23
Yamhill/Maris Hobbit//Druchamp	106.23	19.23	.44	66.25
Yamhill/Druchamp//Stephens	108.75	18.77	.47	68.91
Yamhill/Druchamp//Daws	110.15	23.26	.47	78.68
Yamhill/Druchamp//Maris Hobbit	95.99	20.13	.49	78.03
Stephens/Daws//Yamhill	104.99	22.06	.48	74.84
Stephens/Daws//Maris Hobbit	89.82	22.94	.49	77.93
Stephens/Daws//Druchamp	108.54	22.37	.46	73.89

Table 13 (continued)

Crosses	Plant height (cm)	Tiller number	Harvest index	Grain yield (gm/plant)
Stephens/Maris Hobbit//Yamhill	94.59	19.12	.49	70.95
Stephens/Maris Hobbit//Daws	95.04	22.37	.50	77.18
Stephens/Maris Hobbit//Druchamp	104.11	20.88	.46	70.57
Stephens/Druchamp//Yamhill	107.75	20.45	.45	68.69
Stephens/Druchamp//Daws	105.23	23.54	.47	74.62
Stephens/Druchamp//Maris Hobbit	92.28	20.76	.49	74.23
Daws/Druchamp//Yamhill	110.05	21.77	.45	71.95
Daws/Druchamp//Stephens	104.43	21.11	.48	69.99
Daws/Druchamp//Maris Hobbit	94.09	20.52	.51	73.67
Daws/Maris Hobbit//Yamhill	102.02	20.43	.49	76.30
Daws/Maris Hobbit//Stephens	91.51	22.15	.51	75.73
Daws/Maris Hobbit//Druchamp	108.23	20.96	.46	71.39
Maris Hobbit/Druchamp//Yamhill	101.94	19.20	.47	70.32
Maris Hobbit/Druchamp//Stephens	97.87	18.75	.49	70.03
Maris Hobbit/Druchamp//Daws	98.99	21.01	.50	75.12
Difference required for significance	4.11	ns	.024	7.47

ns = No comparison due to nonsignificant difference.

Table 14. Performance of F_2s for plant height, tiller number, harvest index, and grain yield of three-way crosses grown at the Hyslop location.

Crosses	Plant height (cm)	Tiller number	Harvest index	Grain yield (gm/plant)
Yamhill/Stephens//Daws	104.50	22.78	.47	72.06
Yamhill/Stephens//Maris Hobbit	86.17	19.14	.49	67.10
Yamhill/Stephens//Druchamp	110.15	20.80	.44	66.08
Yamhill/Daws//Stephens	99.31	20.36	.46	61.98
Yamhill/Daws//Maris Hobbit	87.81	21.33	.47	70.49
Yamhill/Daws//Druchamp	107.66	21.78	.43	64.11
Yamhill/Maris Hobbit//Stephens	89.92	19.14	.48	64.54
Yamhill/Maris Hobbit//Daws	97.76	21.28	.47	71.36
Yamhill/Maris Hobbit//Druchamp	104.99	21.18	.46	66.38
Yamhill/Druchamp//Stephens	99.86	20.57	.47	65.06
Yamhill/Druchamp//Daws	106.61	21.05	.45	65.58
Yamhill/Druchamp//Maris Hobbit	96.93	21.44	.47	70.87
Stephens/Daws//Yamhill	100.43	21.02	.46	67.91
Stephens/Daws//Maris Hobbit	92.93	21.93	.49	73.60
Stephens/Daws//Druchamp	108.18	21.65	.44	67.47

Table 14 (continued)

Crosses	Plant height (cm)	Tiller number	Harvest index	Grain yield (gm/plant)
Stephens/Maris Hobbit//Yamhill	95.95	21.78	.46	71.35
Stephens/Maris Hobbit//Daws	91.60	23.67	.49	73.37
Stephens/Maris Hobbit//Druchamp	95.69	21.30	.46	67.61
Stephens/Druchamp//Yamhill	102.02	19.90	.45	65.97
Stephens/Druchamp//Daws	105.15	23.58	.45	67.73
Stephens/Druchamp//Maris Hobbit	89.06	20.06	.48	67.74
Daws/Druchamp//Yamhill	103.50	21.39	.44	67.75
Daws/Druchamp//Stephens	99.36	21.57	.47	67.09
Daws/Druchamp//Maris Hobbit	95.67	21.77	.48	71.92
Daws/Maris Hobbit//Yamhill	101.05	18.50	.47	69.34
Daws/Maris Hobbit//Stephens	89.43	21.26	.48	69.94
Daws/Maris Hobbit//Druchamp	99.90	20.90	.43	61.25
Maris Hobbit/Druchamp//Yamhill	98.69	19.01	.46	67.60
Maris Hobbit/Druchamp//Stephens	94.95	19.73	.43	68.50
Maris Hobbit/Druchamp//Daws	101.06	22.34	.46	69.93
Difference required for significance	5.67	2.35	.009	ns

ns = No comparison due to nonsignificant difference.

Progenies of the crosses Daws/Druchamp//Maris Hobbit and Daws/Maris Hobbit//Stephens had the highest harvest index (.51) in F_1 but this was not true in F_2. The highest harvest index in F_2 was the progenies of the crosses Yamhill/Stephens//Maris Hobbit, Stephens/Daws//Maris Hobbit and Stephens/Maris Hobbit//Daws (.49). Progenies of the cross Yamhill/Daws//Druchamp had the lowest harvest index (.43) in both F_1 and F_2.

For grain yield, the F_1s of the cross Yamhill/Druchamp//Daws was the highest (78.68 gm/plant) while F_1s of the cross Yamhill/Stephens//Druchamp had the lowest grain yield (62.49 gm/plant). Among the F_2s however, no significant difference for grain yield was found.

Three-way crosses resulting from different parental combinations and different parental orders are compared for plant height, harvest index, and grain yield in the F_1, and for plant height, tiller number, and harvest index in the F_2 in Table 15. Tiller number in the F_1 and grain yield in the F_2 were omitted because there were no significant differences in either trait. The combination Yamhill, Daws, Druchamp gave the tallest progenies in both F_1 and F_2 generations (109.79 cm for F_1 and 105.92 cm for F_2). The combination Stephens, Daws, Maris Hobbit gave the shortest progenies (92.12 cm) but it was not significantly different from the combination Yamhill, Stephens, Maris Hobbit which was the shortest in F_2 (90.68 cm).

Table 15. Comparisons of the performance of F_1 and F_2 generations resulting from different parental combinations and different parental orders for plant height, tiller number, harvest index, and grain yield of three-way crosses grown at the Hyslop location.

Combinations and Orders of Crosses	F_1			F_2		
	Plant height (cm)	Harvest index	Grain yield (gm/plant)	Plant height (cm)	Tiller number	Harvest Index
Parents combined: Yamhill, Stephens, Daws						
Yamhill/Stephens//Daws	102.67	.47	66.54	104.50	22.78	.47
Yamhill/Daws//Stephens	100.68	.47	70.53	99.31	20.36	.46
Stephens/Daws//Yamhill	104.49	.48	74.84	100.43	21.02	.46
Mean	102.61	.47	70.64	101.41	21.38	.46
Parents combined: Yamhill, Stephens, Maris Hobbit						
Yamhill/Stephens//Maris Hobbit	89.18	.47	66.76	86.17	19.14	.49
Yamhill/Maris Hobbit//Stephens	99.44	.50	76.78	89.92	19.14	.48
Stephens/Maris Hobbit//Yamhill	94.59	.49	70.95	95.95	21.78	.46
Mean	94.40	.49	71.49	90.68	20.02	.48
Parents combined: Stephens, Daws, Druchamp						
Stephens/Daws//Druchamp	108.54	.46	73.89	108.18	21.65	.44
Stephens/Druchamp//Daws	105.23	.47	74.62	105.15	23.58	.45
Daws/Druchamp//Stephens	104.43	.48	69.99	99.36	21.57	.47
Mean	106.07	.47	72.93	104.23	22.27	.45

Table 15 (continued)

Combinations and Orders of Crosses	F1 Plant height (cm)	F1 Harvest index	F1 Grain yield (gm/plant)	F2 Plant height (cm)	F2 Tiller number	F2 Harvest index
Parents combined: Yamhill, Daws, Maris Hobbit						
Yamhill/Daws//Maris Hobbit	91.98	.48	71.44	87.81	21.33	.47
Yamhill/Maris Hobbit//Daws	100.25	.49	77.23	97.76	21.28	.47
Daws/Maris Hobbit//Yamhill	102.02	.49	76.30	101.05	18.50	.47
Mean	98.08	.49	74.99	95.54	20.37	.47
Parents combined: Yamhill, Daws, Druchamp						
Yamhill/Daws//Druchamp	109.02	.43	66.24	107.66	21.78	.43
Yamhill/Druchamp//Daws	110.15	.47	78.68	106.61	21.05	.45
Daws/Druchamp//Yamhill	110.05	.45	71.95	103.50	21.39	.44
Mean	109.79	.45	72.29	105.92	21.41	.44
Parents combined: Yamhill, Maris Hobbit, Druchamp						
Yamhill/Maris Hobbit//Druchamp	106.23	.44	66.25	104.99	21.18	.46
Yamhill/Druchamp//Maris Hobbit	95.95	.49	78.03	96.93	21.44	.47
Maris Hobbit/Druchamp//Yamhill	101.94	.47	70.32	98.69	19.01	.46
Mean	101.37	.47	71.53	100.20	20.54	.46
Parents combined: Stephens, Maris Hobbit, Daws						
Stephens/Daws//Maris Hobbit	89.82	.49	77.93	92.93	21.93	.49
Stephens/Maris Hobbit//Daws	95.04	.50	77.18	91.60	23.67	.49
Daws/Maris Hobbit//Stephens	91.51	.51	75.73	89.43	21.06	.48
Mean	92.12	.50	76.94	91.32	22.22	.49

Table 15 (continued)

Combinations and Orders of Crosses	F_1 Plant height (cm)	F_1 Harvest index	F_1 Grain yield (gm/plant)	F_2 Plant height (cm)	F_2 Tiller number	F_2 Harvest index
Parents combined: Yamhill, Stephens, Druchamp						
Yamhill/Stephens//Druchamp	109.78	.44	62.49	110.15	20.80	.44
Yamhill/Druchamp//Stephens	108.75	.47	68.91	99.86	20.57	.47
Stephens/Druchamp//Yamhill	107.75	.45	68.96	102.02	19.90	.45
Mean	108.76	.45	66.78	104.01	20.42	.45
Parents combined: Stephens, Maris Hobbit, Druchamp						
Stephens/Maris Hobbit//Druchamp	104.11	.46	70.57	95.69	21.30	.46
Stephens/Druchamp//Maris Hobbit	92.28	.49	74.23	89.06	20.06	.48
Maris Hobbit/Druchamp//Stephens	97.87	.49	73.03	94.95	19.73	.48
Mean	98.09	.48	71.61	93.23	20.36	.47
Parents combined: Daws, Maris Hobbit, Druchamp						
Daws/Maris Hobbit//Druchamp	108.23	.46	71.39	99.90	20.90	.43
Daws/Druchamp//Maris Hobbit	94.09	.51	73.67	95.67	21.77	.48
Maris Hobbit/Druchamp//Daws	98.99	.50	75.12	101.06	22.34	.46
Mean	104.44	.49	73.39	98.88	21.67	.46
Difference required for significance						
- Combination mean	2.38	.014	4.32	3.33	1.36	.005
- Order of crosses	4.11	.024	7.47	5.76	2.35	.009

It might be noted that the combination Yamhill, Daws, Druchamp had the maximum total GCA for plant height, while the combination Stephens, Daws, Maris Hobbit had the lowest total GCA (Table 7).

Significant differences between orders of parents within the same combinations for plant height were found only when Maris Hobbit with a low GCA, and Druchamp with a high GCA were involved.

It can also be noted in Table 15 that where Maris Hobbit was used as the top cross parent it had more influence in shortening the plant height of the crosses than when it was in the original single cross. These observations were true in both F_1 and F_2. For harvest index, the combination Stephens, Daws, Maris Hobbit gave the highest value while the combination Yamhill, Daws, Druchamp gave the lowest on the average in both generations. As in plant height, the combination with highest total GCA for harvest index also gave progenies with the highest harvest index, and the combination with lowest total GCA gave the lowest harvest index. Similar results were found for the order of the crosses where a parent was used for plant height. Differences among crosses within the same combination were found when either Maris Hobbit with high GCA or Druchamp with a low GCA were involved. However, Druchamp as a top cross parent was more important in reducing the harvest index of its progeny than Maris Hobbit was in increasing it.

For tiller number, significant differences were found only in the F_2. The combination Stephens, Daws, Maris Hobbit gave the highest tiller number in the F_2 (22.22). It should be noted that this combination was one of the combinations with highest GCA for tiller number (Table 7).

For grain yield the combination Stephens, Daws, Maris Hobbit gave progenies with the highest grain yield (76.94 gm/plant), while the combination Stephens, Druchamp, Yamhill gave the lowest grain yield progenies (66.78 gm/plant in the F_1). No significant difference in grain yield was found in the F_2. Similar results regarding GCA noted for plant height, tiller number and harvest index, were also observed for grain yield. The combination which was comprised of parents with maximum total GCA gave the highest grain yield and the combination with the lowest total GCA gave the lowest grain yield (Table 7 and Table 15). No difference due to the order in which parents were combined was found when all parents in the combinations had high GCA, or when all parents in the combinations had low GCA for grain yield. Significant differences in grain yield due to parental order were found within the combination Yamhill, Stephens, Maris Hobbit; Yamhill, Daws, Druchamp and Yamhill, Maris Hobbit, Druchamp.

Actual and predicted performance given by the two predicting models for plant height of F_1 and F_2 of three-way crosses are shown in Table 16. Significantly high

Table 16. Actual and predicted plant heights (cm) for three-way crosses grown at the Hyslop location.

Crosses	Predicted Values Model I	Model II	Actual Values F_1	F_2
Yamhill/Stephens//Daws	90.94	101.62	102.67	104.50
Yamhill/Stephens//Maris Hobbit	88.21	90.50	89.18	86.17
Yamhill/Stephens//Druchamp	104.03	111.42	112.42	109.79
Yamhill/Daws//Stephens	93.18	98.16	100.68	99.31
Yamhill/Daws//Maris Hobbit	85.98	91.78	91.98	87.81
Yamhill/Daws//Druchamp	101.80	113.24	109.02	107.66
Yamhill/Maris Hobbit//Stephens	91.81	95.97	94.44	89.92
Yamhill/Maris Hobbit//Daws	87.34	100.71	100.25	97.67
Yamhill/Maris Hobbit//Druchamp	100.43	106.61	106.23	104.99
Yamhill/Druchamp//Stephens	99.73	108.12	108.75	99.86
Yamhill/Druchamp//Daws	95.25	112.39	110.15	106.61
Yamhill/Druchamp//Maris Hobbit	92.52	97.83	95.99	96.93
Stephens/Daws//Yamhill	93.26	106.96	104.49	100.43
Stephens/Daws//Maris Hobbit	85.90	89.72	89.82	92.93
Stephens/Daws//Druchamp	107.72	113.55	108.54	108.18
Stephens/Maris Hobbit//Yamhill	91.89	98.03	94.59	95.95
Stephens/Maris Hobbit//Daws	87.27	91.91	95.04	91.60
Stephens/Maris Hobbit//Druchamp	100.36	106.92	104.11	95.69
Stephens/Druchamp//Yamhill	99.80	107.80	107.75	102.02
Stephens/Druchamp//Daws	95.10	103.59	105.23	105.15
Stephens/Druchamp//Maris Hobbit	92.44	94.77	92.28	89.06
Daws/Druchamp//Yamhill	97.57	111.26	110.05	103.50
Daws/Druchamp//Stephens	97.41	102.78	104.42	99.36
Daws/Druchamp//Maris Hobbit	90.21	96.06	94.09	95.67
Daws/Maris Hobbit//Yamhill	89.66	101.49	102.02	101.05
Daws/Maris Hobbit//Stephens	89.50	90.63	92.51	89.43
Daws/Maris Hobbit//Druchamp	98.12	107.74	108.23	99.90
Maris Hobbit/Druchamp//Yamhill	96.20	102.33	101.94	98.69
Maris Hobbit/Druchamp//Daws	91.58	102.69	98.99	101.06
Maris Hobbit/Druchamp//Stephens	96.05	100.59	97.87	94.95
Correlation Coefficients for Model I			0.82**	0.70**
Correlation Coefficients for Model II			0.96**	0.88**

**Significant at one percent probability level.

correlation coefficients were found with both models (Model I: r = .82 for F_1 and r = .70 for F_2, Model II: r = .96 for F_1 and r = .88 for F_2). For tiller number, the actual and predicted performance with their correlation coefficients are presented in Table 17. Significantly high correlation coefficients were found for both models (Model I: r = .51 for F_1 and r = .65 for F_2, Model II: r = .47 for F_1 and r = .46 for F_2). Actual and predicted harvest index are shown in Table 18 along with their correlation coefficients. Both models gave significantly high correlation coefficients between actual and predicted harvest index (Model I: r = .79 for F_1 and r = .81 for F_2, Model II: r = .79 for F_1 and r = .83 for F_2). Actual and predicted grain yield, given by two predicting models and their correlation coefficients are presented in Table 19. Both models predicted equally well with intermediate but significant correlation coefficients (Model I: r = .50 for F_1 and r = .54 for F_2, Model II: r = .51 for F_1 and r = .48 for F_2).

The comparison of the correlation coefficients between actual and predicted performance of four traits given by Model I and Model II are provided in Table 20.

Actual and Predicted Performance of Double Crosses

The performance of F_1 and F_2 of fifteen double crosses are given in Table 21. There were highly significant differences for plant height and harvest index among F_1s, and

Table 17. Actual and predicted tiller numbers for three-way crosses grown at the Hyslop location.

Crosses	Predicted Values Model I	Predicted Values Model II	Actual Values F_1	Actual Values F_2
Yamhill/Stephens//Daws	22.62	22.00	19.85	22.78
Yamhill/Stephens//Maris Hobbit	19.48	20.27	18.82	19.14
Yamhill/Stephens//Druchamp	21.44	20.33	17.70	20.80
Yamhill/Daws//Stephens	21.44	22.27	30.98	20.36
Yamhill/Daws//Maris Hobbit	20.96	20.16	20.05	21.33
Yamhill/Daws//Druchamp	22.61	20.19	20.58	21.78
Yamhill/Maris Hobbit//Stephens	20.02	21.52	20.98	19.14
Yamhill/Maris Hobbit//Daws	22.37	21.14	20.87	21.38
Yamhill/Maris Hobbit//Druchamp	21.19	19.96	19.23	21.18
Yamhill/Druchamp//Stephens	20.85	21.74	18.77	20.57
Yamhill/Druchamp//Daws	23.20	21.05	23.60	21.05
Yamhill/Druchamp//Maris Hobbit	20.36	19.84	20.13	21.44
Stephens/Daws//Yamhill	21.05	21.00	22.06	21.02
Stephens/Daws//Maris Hobbit	21.35	21.66	22.94	21.93
Stephens/Daws//Druchamp	23.00	21.52	22.37	21.65
Stephens/Maris Hobbit//Yamhill	19.63	20.20	19.12	21.78
Stephens/Maris Hobbit//Daws	22.77	22.41	22.37	23.67
Stephens/Maris Hobbit//Druchamp	21.59	21.29	20.88	21.30
Stephens/Druchamp//Yamhill	20.46	20.14	20.45	19.90
Stephens/Druchamp//Daws	23.59	22.32	23.54	23.58
Stephens/Druchamp//Maris Hobbit	20.76	21.34	20.76	20.06
Daws/Druchamp//Yamhill	21.63	19.86	21.77	21.39
Daws/Druchamp//Stephens	22.42	22.46	21.11	21.57
Daws/Druchamp//Maris Hobbit	24.77	21.52	20.52	21.77
Daws/Maris Hobbit//Yamhill	20.81	19.75	20.42	18.50
Daws/Maris Hobbit//Stephens	21.59	22.51	22.15	21.06
Daws/Maris Hobbit//Druchamp	22.76	21.15	20.96	20.90
Maris Hobbit/Druchamp//Yamhill	20.22	18.88	19.20	19.01
Maris Hobbit/Druchamp//Stephens	21.00	21.71	18.75	19.73
Maris Hobbit/Druchamp//Daws	23.35	21.47	21.01	22.34
Correlation Coefficients for Model I			0.51**	0.65**
Correlation Coefficients for Model II			0.47**	0.46**

**Significant at one percent probability level.

Table 18. Actual and predicted harvest index for three-way crosses grown at the Hyslop location.

Crosses	Predicted Values Model I	Model II	Actual Values F_1	F_2
Yamhill/Stephens//Daws	.47	.49	.47	.47
Yamhill/Stephens//Maris Hobbit	.48	.51	.47	.49
Yamhill/Stephens//Druchamp	.43	.44	.44	.44
Yamhill/Daws//Stephens	.47	.49	.47	.46
Yamhill/Daws//Maris Hobbit	.48	.51	.48	.47
Yamhill/Daws//Druchamp	.43	.44	.43	.43
Yamhill/Maris Hobbit//Stephens	.48	.49	.50	.48
Yamhill/Maris Hobbit//Daws	.48	.50	.49	.47
Yamhill/Maris Hobbit//Druchamp	.44	.45	.44	.46
Yamhill/Druchamp//Stephens	.45	.46	.47	.47
Yamhill/Druchamp//Daws	.45	.46	.47	.45
Yamhill/Druchamp//Maris Hobbit	.46	.49	.49	.47
Stephens/Daws//Yamhill	.47	.48	.48	.46
Stephens/Daws//Maris Hobbit	.49	.51	.49	.49
Stephens/Daws//Druchamp	.44	.45	.46	.44
Stephens/Maris Hobbit//Yamhill	.47	.49	.49	.46
Stephens/Maris Hobbit//Daws	.48	.51	.50	.49
Stephens/Maris Hobbit//Druchamp	.44	.46	.46	.46
Stephens/Druchamp//Yamhill	.45	.45	.45	.45
Stephens/Druchamp//Daws	.46	.47	.47	.45
Stephens/Druchamp//Maris Hobbit	.47	.49	.49	.48
Daws/Druchamp//Yamhill	.45	.45	.48	.47
Daws/Druchamp//Stephens	.46	.47	.48	.57
Daws/Druchamp//Maris Hobbit	.47	.49	.51	.48
Daws/Maris Hobbit//Yamhill	.47	.49	.49	.47
Daws/Maris Hobbit//Stephens	.48	.50	.51	.48
Daws/Maris Hobbit//Druchamp	.44	.46	.46	.43
Maris Hobbit/Druchamp//Yamhill	.45	.47	.47	.46
Maris Hobbit/Druchamp//Stephens	.46	.48	.49	.48
Maris Hobbit/Druchamp//Daws	.46	.48	.50	.46
Correlation Coefficients for Model I			0.79**	0.81**
Correlation Coefficients for Model II			0.79**	0.83**

**Significant at one percent probability level.

Table 19. Actual and predicted grain yields (gm/plant) for three-way crosses grown at the Hyslop location.

Crosses	Predicted Values		Actual Values	
	Model I	Model II	F_1	F_2
Yamhill/Stephens//Daws	73.34	77.70	66.54	72.06
Yamhill/Stephens//Maris Hobbit	70.47	79.40	66.67	67.10
Yamhill/Stephens//Druchamp	67.57	72.29	62.49	66.08
Yamhill/Daws//Stephens	71.01	74.53	70.53	61.98
Yamhill/Daws//Maris Hobbit	72.75	77.80	71.44	70.49
Yamhill/Daws//Druchamp	69.85	71.04	66.24	64.11
Yamhill/Maris Hobbit//Stephens	69.63	78.70	76.78	64.54
Yamhill/Maris Hobbit//Daws	74.18	80.27	77.23	71.36
Yamhill/Maris Hobbit//Druchamp	68.41	68.06	66.25	61.38
Yamhill/Druchamp//Stephens	68.18	71.59	68.91	65.06
Yamhill/Druchamp//Daws	72.73	77.73	78.68	65.58
Yamhill/Druchamp//Maris Hobbit	69.86	72.29	78.03	70.87
Stephens/Daws//Yamhill	71.98	78.05	74.84	67.91
Stephens/Daws//Maris Hobbit	71.84	80.91	77.93	73.60
Stephens/Daws//Druchamp	68.94	75.50	73.50	67.47
Stephens/Maris Hobbit//Yamhill	72.22	75.59	70.95	71.35
Stephens/Maris Hobbit//Daws	73.27	76.75	77.18	73.37
Stephens/Maris Hobbit//Druchamp	67.50	72.53	70.57	67.61
Stephens/Druchamp//Yamhill	69.09	71.36	68.96	65.97
Stephens/Druchamp//Daws	71.82	74.21	74.62	67.73
Stephens/Druchamp//Maris Hobbit	68.95	75.40	74.25	67.74
Daws/Druchamp//Yamhill	71.36	74.52	71.95	67.75
Daws/Druchamp//Stephens	69.55	75.47	69.99	67.75
Daws/Druchamp//Maris Hobbit	71.22	73.81	73.67	71.92
Daws/Maris Hobbit//Yamhill	72.82	78.75	76.30	69.34
Daws/Maris Hobbit//Stephens	70.99	78.34	75.73	69.94
Daws/Maris Hobbit//Druchamp	69.78	71.27	71.39	61.60
Maris Hobbit/Druchamp//Yamhill	69.63	72.06	70.32	67.60
Maris Hobbit/Druchamp//Stephens	68.11	79.63	70.03	68.50
Maris Hobbit/Druchamp//Daws	72.67	76.78	75.12	69.93
Correlation Coefficients for Model I			0.50**	0.54**
Correlation Coefficients for Model II			0.51**	0.48**

**Significant at one percent probability level.

Table 20. Comparison of the correlation coefficients between actual and predicted performance given by two predicting models for plant height, tiller number, harvest index, and grain yield for three-way crosses grown at the Hyslop location.

Model	Plant height		Tiller number		Harvest index		Grain yield	
	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
I	0.82**	0.70**	0.51**	0.65**	0.79**	0.81**	0.50**	0.54**
II	0.96**	0.88**	0.47**	0.46**	0.79**	0.83**	0.51**	0.48**

**Significant at one percent probability level.

n = 30 in all relationships.

Table 21. Performance of F_1 and F_2 for plant height, tiller number, harvest index and grain yield of double crosses grown at the Hyslop location.

	F_1				F_2			
Crosses	Plant height (cm)	Tiller number	Harvest index	Grain yield (gm/ plant)	Plant height (cm)	Tiller number	Harvest index	Grain yield (gm/ plant)
Yamhill/Stephens//Daws/Maris Hobbit	95.98	23.50	.48	74.67	94.75	22.23	.47	68.58
Yamhill/Stephens//Daws/Druchamp	107.65	22.52	.45	72.46	101.94	21.27	.43	64.45
Yamhill/Stephens//Maris Hobbit/Druchamp	100.84	19.76	.47	74.04	98.24	21.42	.47	70.37
Yamhill/Daws//Stephens/Maris Hobbit	96.85	21.21	.49	74.74	88.46	22.54	.47	69.42
Yamhill/Daws//Stephens/Druchamp	108.10	22.64	.46	74.63	105.11	23.65	.45	71.72
Yamhill/Daws//Maris Hobbit/Druchamp	110.55	21.96	.47	77.34	102.35	20.83	.46	66.98
Yamhill/Maris Hobbit//Stephens/Daws	96.81	23.10	.49	80.75	97.01	21.81	.48	71.39
Yamhill/Maris Hobbit//Stephens/Druchamp	101.07	20.23	.47	77.36	101.77	20.05	.45	67.64
Yamhill/Maris Hobbit//Daws/Druchamp	105.15	23.53	.47	83.77	100.17	20.97	.47	66.68
Yamhill/Druchamp//Stephens/Daws	106.97	23.37	.47	76.99	99.80	22.16	.45	66.30
Yamhill/Druchamp//Stephens/Maris Hobbit	95.87	22.06	.47	76.03	97.61	18.28	.47	63.51
Yamhill/Druchamp//Daws/Maris Hobbit	106.22	22.09	.48	78.84	102.66	20.31	.47	65.48
Stephens/Daws//Maris Hobbit/Druchamp	95.37	22.55	.48	73.59	96.83	20.70	.47	67.99
Stephens/Druchamp//Daws/Maris Hobbit	99.81	22.36	.48	76.26	93.94	21.22	.47	67.69
Stephens/Maris Hobbit//Daws/Druchamp	97.39	21.73	.47	72.55	95.32	20.15	.47	65.45
Difference required for significance	4.90	ns	.006	ns	5.97	2.31	.051	ns

ns = No comparison due to nonsignificant difference.

for plant height, tiller number, and harvest index among F_2s. The comparisons of F_1s and F_2 of double crosses resulting from different parental combinations and different parental orders in the crosses are shown in Table 22. Tiller number in the F_1 and grain yield in the F_1 and F_2 were omitted because no significant differences were found for these traits. The data in Table 22 indicate that the combination Yamhill, Stephens, Daws, Druchamp gave the tallest progeny in both F_1 and F_2 (107.57 cm for F_1 and 102.28 cm for F_2), while Yamhill, Stephens, Daws, Maris Hobbit gave the shortest progeny in both generations (96.55 cm and 93.41 cm for F_1 and F_2 respectively). The order of parental combination was significant for plant height when the four parents, Yamhill, Stephens, Maris Hobbit, and Druchamp, were involved. The cross Yamhill/Maris Hobbit//Stephens/Druchamp was the tallest (101.07 cm) and the cross Yamhill/Druchamp//Stephens/Maris Hobbit was the shortest (95.87 cm). The order of combination also proved significant when the four parents were Yamhill, Daws, Maris Hobbit, and Druchamp. The cross Yamhill/Daws//Maris Hobbit/Druchamp was the tallest (110.55 cm) and the cross Yamhill/Maris Hobbit//Daws/Druchamp was the shortest (105.15 cm). In the F_2, changes in the order of parental combination of Yamhill, Stephens, Daws, and Maris Hobbit yielded statistical differences for plant height. The cross Yamhill/Maris Hobbit//Stephens/Daws gave the tallest

Table 22. Comparison of the performance of F_1 and F_2 resulting from different parental combinations and different parental orders for plant height, tiller number, and harvest index of double crosses grown at the Hyslop location.

Combinations and Orders of Crosses	F_1 Plant height (cm)	F_1 Harvest index	F_2 Plant height (cm)	F_2 Tiller number	F_2 Harvest index
Parents combined: Yamhill, Stephens, Daws, Maris Hobbit					
Yamhill/Stephens//Daws/Maris Hobbit	95.98	.48	94.75	22.19	.47
Yamhill/Daws//Stephens/Maris Hobbit	96.85	.49	88.46	22.54	.47
Yamhill/Maris Hobbit//Stephens/Daws	96.61	.49	97.01	21.81	.48
Mean	96.55	.49	93.41	22.19	.47
Parents combined: Yamhill, Stephens, Daws, Druchamp					
Yamhill/Stephens//Daws/Druchamp	107.65	.45	101.94	21.27	.43
Yamhill/Daws//Stephens/Druchamp	108.10	.46	105.11	23.65	.45
Yamhill/Druchamp//Stephens/Daws	106.97	.47	99.80	22.16	.45
Mean	107.57	.46	102.28	22.36	.44
Parents combined: Yamhill, Stephens, Maris Hobbit, Druchamp					
Yamhill/Stephens//Maris Hobbit/Druchamp	100.84	.47	98.24	21.42	.47
Yamhill/Maris Hobbit//Stephens/Druchamp	101.07	.47	101.77	20.05	.45
Yamhill/Druchamp//Stephens/Maris Hobbit	95.87	.47	97.61	18.28	.47
Mean	99.26	.47	99.21	19.92	.46
Parents combined: Yamhill, Daws, Maris Hobbit, Druchamp					
Yamhill/Daws//Maris Hobbit/Druchamp	110.55	.47	102.35	20.83	.46
Yamhill/Maris Hobbit//Daws/Druchamp	105.15	.47	100.17	20.98	.47

Table 22 (continued)

Combinations and Orders of Crosses	F_1 Plant height (cm)	F_1 Harvest index	F_2 Plant height (cm)	F_2 Tiller number	F_2 Harvest index
Yamhill/Druchamp//Daws/Maris Hobbit	106.22	.48	102.66	20.31	.47
Mean	107.31	.47	101.73	20.71	.47
Parents combined: Stephens, Daws, Maris Hobbit, Druchamp					
Stephens/Daws//Maris Hobbit/Druchamp	95.36	.48	96.82	20.70	.47
Stephens/Maris Hobbit//Daws/Druchamp	97.39	.47	95.32	20.15	.47
Stephens/Druchamp//Daws/Maris Hobbit	99.81	.48	93.94	21.22	.47
Mean	97.52	.48	95.36	20.69	.47
Difference required for significance:					
- Combination mean	2.83	.003	3.45	1.33	.009
- Order of crosses	4.90	.006	5.97	2.31	.015

progeny (97.01 cm) and the cross Yamhill/Daws//Stephens/ Maris Hobbit gave the shortest progeny (88.46 cm).

It can be noted that when two parents with high GCA and two parents with low GCA for plant height were combined the high GCA/low GCA//high GCA/low GCA order gave the tallest progeny (Table 7 and Table 22).

For tiller number, there were no significant differences among F_1s but the F_2 double crosses were statistically different. Only the combination Yamhill, Stephens, Maris Hobbit, Druchamp gave progeny with a lower tiller number than all others. The order of parental combination produced significant differences in tiller number for this combination only. The cross Yamhill/Druchamp//Stephens/Maris Hobbit gave ghe lowest tiller number (18.28), while the cross Yamhill/Stephens//Maris Hobbit/Druchamp gave the highest tiller number in the combination(21.42).

The combination Yamhill, Stephens, Daws, Maris Hobbit resulted in progenies with a significantly high harvest index (.49 and .47 in the F_1 and F_2, respectively). The combination Yamhill, Stephens, Daws, Druchamp resulted in progenies with the lowest harvest index in both F_1 and F_2 (.46 and .44, respectively). The lowest combination also was the only combination which gave a significantly lower and different value for harvest index compared to other combinations in F_2.

Similar results for GCA estimates as noted in three-way crosses were obtained. Combinations where the sum of parental GCA was high gave higher performing progenies, while combinations where the sum of parental GCA was low gave progenies with lower performance.

Actual and predicted performance of double crosses given by three predicting models with their respective correlation coefficients for plant height, tiller number, harvest index, and grain yield are shown in Tables 23, 24, 25, and 26 respectively. The comparison of the correlation coefficients for each model are presented in Table 27. All three models predict equally well for plant height of both F_1 and F_2 (Model I: $r = .90$, for F_1, and $r = .74$ for F_2, Model II: $r = .81$ for F_1, and $r = .76$ for F_2, Model III: $r = .64$ for F_1, and $r = .68$ for F_2). For tiller number only Model III gave a significant correlation coefficient for F_1 ($r = .54$). For harvest index all three models predicted equally well with high and significant r values (Model I: $r = .84$ for F_1 and $r = .72$ for F_2, Model II: $r = .84$ for F_1 and $r = .72$ for F_2, Model III: $r = .82$ for F_1 and $r = .65$ for F_2). In predicting grain yield in double crosses, only Model III gave a significantly high correlation coefficient for F_1 (.48) but none of the three models could satisfac- factorily predict grain yield for F_2.

Table 23. Actual and predicted plant heights (cm) of double crosses grown at the Hyslop location.

Crosses	Predicted Values			Actual Values	
	Model I	Model II	Model III	F_1	F_2
Yamhill/Stephens//Daws/Maris Hobbit	86.46	96.06	89.58	95.98	94.75
Yamhill/Stephens//Daws/Druchamp	107.66	107.02	97.47	107.65	101.94
Yamhill/Stephens//Maris Hobbit/Druchamp	101.74	101.46	96.12	100.84	98.24
Yamhill/Daws//Stephens/Maris Hobbit	96.46	94.47	89.58	96.85	88.46
Yamhill/Daws//Stephens/Druchamp	107.66	105.70	97.47	108.10	105.11
Yamhill/Daws//Maris Hobbit/Druchamp	101.94	102.51	93.89	100.55	102.35
Yamhill/Maris Hobbit//Stephens/Daws	96.46	98.34	89.58	96.81	97.01
Yamhill/Maris Hobbit//Stephens/Druchamp	101.74	101.29	96.12	101.07	101.77
Yamhill/Maris Hobbit//Daws/Druchamp	103.59	103.66	93.89	105.15	100.17
Yamhill/Druchamp//Stephens/Daws	107.66	110.26	97.49	106.97	99.80
Yamhill/Druchamp//Stephens/Maris Hobbit	101.74	102.48	96.12	95.87	97.61
Yamhill/Druchamp//Daws/Maris Hobbit	105.28	104.61	93.89	106.22	102.66
Stephens/Daws//Maris Hobbit/Druchamp	100.08	101.64	93.81	95.37	96.82
Stephens/Maris Hobbit//Daws/Druchamp	100.08	99.42	93.81	97.39	95.32
Stephens/Druchamp//Daws/Maris Hobbit	100.08	99.18	93.81	99.81	93.94
Correlation coefficient for Model I				.90**	.74**
Correlation coefficient for Model II				.81**	.76**
Correlation coefficient for Model III				.64**	.68**

**Significant at one percent probability level.

Table 24. Actual and predicted tiller numbers of double crosses grown at the Hyslop location.

Crosses	Predicted Values			Actual Values	
	Model I	Model II	Model III	F_1	F_2
Yamhill/Stephens//Daws/Maris Hobbit	21.21	21.13	21.20	23.50	22.23
Yamhill/Stephens//Daws/Druchamp	21.22	21.16	22.03	22.52	21.27
Yamhill/Stephens//Maris Hobbit/Druchamp	20.56	20.30	20.61	19.76	21.42
Yamhill/Daws//Stephens/Maris Hobbit	21.23	21.22	21.20	21.21	22.51
Yamhill/Daws//Stephens/Druchamp	21.22	21.23	22.03	22.64	23.65
Yamhill/Daws//Maris Hobbit/Druchamp	20.39	20.18	21.78	21.96	20.83
Yamhill/Maris Hobbit//Stephens/Daws	21.23	21.33	21.20	23.10	21.81
Yamhill/Maris Hobbit//Stephens/Druchamp	20.56	20.74	20.61	20.23	20.05
Yamhill/Maris Hobbit//Daws/Druchamp	20.39	20.55	21.78	23.53	20.97
Yamhill/Druchamp//Stephens/Daws	21.22	21.26	22.03	23.37	22.16
Yamhill/Druchamp//Stephens/Maris Hobbit	20.56	20.67	20.61	22.06	18.28
Yamhill/Druchamp//Daws/Maris Hobbit	20.39	20.45	21.78	22.09	20.31
Stephens/Daws//Maris Hobbit/Druchamp	21.75	21.59	22.18	22.55	20.70
Stephens/Maris Hobbit//Daws/Druchamp	21.75	21.85	22.18	21.73	20.15
Stephens/Druchamp//Daws/Maris Hobbit	21.75	21.78	22.18	22.36	21.22
Correlation coefficient for Model I				.27	.32
Correlation coefficient for Model II				.32	.25
Correlation coefficient for Model III				.54**	.28

**Significant at one percent probability level.

Table 25. Actual and predicted harvest index of double crosses grown at the Hyslop location.

Crosses	Predicted Values: Model I	Model II	Model III	Actual Values: F_1	F_2
Yamhill/Stephens//Daws/Maris Hobbit	.50	.50	.48	.48	.47
Yamhill/Stephens//Daws/Druchamp	.46	.46	.45	.45	.43
Yamhill/Stephens//Maris Hobbit/Druchamp	.47	.47	.46	.47	.47
Yamhill/Daws//Stephens/Maris Hobbit	.50	.50	.48	.49	.47
Yamhill/Daws//Stephens/Druchamp	.46	.46	.46	.46	.45
Yamhill/Daws//Maris Hobbit/Druchamp	.48	.48	.46	.47	.46
Yamhill/Maris Hobbit//Stephens/Daws	.50	.50	.48	.49	.48
Yamhill/Maris Hobbit//Stephens/Druchamp	.47	.47	.46	.47	.45
Yamhill/Maris Hobbit//Daws/Druchamp	.48	.47	.46	.47	.47
Yamhill/Druchamp//Stephens/Daws	.46	.46	.45	.47	.45
Yamhill/Druchamp//Stephens/Maris Hobbit	.47	.48	.46	.47	.47
Yamhill/Druchamp//Daws/Maris Hobbit	.48	.48	.46	.48	.47
Stephens/Daws//Maris Hobbit/Druchamp	.48	.48	.46	.48	.47
Stephens/Maris Hobbit//Daws/Druchamp	.48	.48	.46	.47	.47
Stephens/Druchamp//Daws/Maris Hobbit	.48	.48	.46	.48	.47
Correlation coefficient for Model I				.84**	.72**
Correlation coefficient for Model II				.84**	.72**
Correlation coefficient for Model III				.82**	.65**

**Significant at one percent probability level.

Table 26. Actual and predicted grain yields (gm/plant) of double grown at the Hyslop location.

Crosses	Predicted Values Model I	Model II	Model III	Actual Values F_1	F_2
Yamhill/Stephens//Daws/Maris Hobbit	78.07	78.55	71.90	74.67	68.58
Yamhill/Stephens//Daws/Druchamp	74.85	75.00	70.46	72.46	64.45
Yamhill/Stephens//Maris Hobbit/Druchamp	76.46	75.85	69.02	74.02	70.37
Yamhill/Daws//Stephens/Maris Hobbit	78.07	76.17	71.94	75.74	69.42
Yamhill/Daws//Stephens/Druchamp	74.85	72.79	70.46	74.63	71.21
Yamhill/Daws//Maris Hobbit/Druchamp	76.37	74.42	71.31	77.38	66.98
Yamhill/Maris Hobbit//Stephens/Daws	78.07	79.48	71.90	80.75	71.39
Yamhill/Maris Hobbit//Stephens/Druchamp	76.46	76.43	69.02	73.36	67.64
Yamhill/Maris Hobbit//Daws/Druchamp	76.37	77.23	71.30	83.77	68.68
Yamhill/Druchamp//Stephens/Daws	74.85	76.78	70.46	76.99	66.30
Yamhill/Druchamp//Stephens/Maris Hobbit	76.46	71.11	69.02	76.03	63.51
Yamhill/Druchamp//Daws/Maris Hobbit	76.37	78.06	71.30	78.84	65.48
Stephens/Daws//Maris Hobbit/Druchamp	77.92	78.21	70.39	75.59	67.99
Stephens/Maris Hobbit//Daws/Druchamp	77.92	77.69	70.39	72.55	66.46
Stephens/Druchamp//Daws/Maris Hobbit	77.92	77.86	70.39	76.26	67.69
Correlation coefficient for Model I				.03	.20
Correlation coefficient for Model II				.23	.25
Correlation coefficient for Model III				.48*	.28

* Significant at five percent probability level.

Table 27. Correlation coefficients between actual and predicted performance for plant height, tiller number, harvest index, and grain yield of double crosses grown at the Hyslop location.

Model	Plant height		Tiller number		Harvest Index		Grain yield	
	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
I	0.90**	0.74**	0.27	0.32	0.84**	0.72**	0.03	0.20
II	0.81**	0.76**	0.32	0.25	0.84**	0.72**	0.20	0.25
III	0.64**	0.68**	0.54**	0.28	0.82**	0.65**	0.48*	0.28

* Significant at five percent probability level.

**Significant at one percent probability level.

n = 15 in all relationships.

Pendleton Location

Evaluation of Parents

In Table 28 are presented the observed mean squares from analysis of variances for parents, F_1s and F_2s, of single, three-way, and double crosses for plant height, tiller number, harvest index, and grain yield at the Pendleton location. It is evident that among 115 genotypes, only plant height was significantly different at this location. Coefficients of variation were 7.60% for plant height, 10.05% for tiller number, 12.84% for harvest index, and 16.80% for grain yield.

From the functional analysis of variance (Table 29), it can be observed that plant height was not significantly different among seven populations (parents, F_1 of single crosses, F_2 of single crosses, F_1 of three-way crosses, F_2 of three-way crosses, F_1 of double crosses and F_2 of double crosses) but it was significantly different within all populations.

Since no significant difference among genotypes for tiller number, harvest index, and grain yield were detected no further comparisons were made for these traits.

The comparisons of the performance of parents for plant height at Pendleton are given in Table 30. There were significant differences between parents for plant height. Maris Hobbit and Yamhill were significantly shorter than the other parents (65.04 cm and 68.03 cm respectively) except Daws. Druchamp was the tallest (87.30 cm) while Stephens

Table 28. Observed mean squares for plant height, tiller number, harvest index, and grain yield for parents, F_1s and F_2s of single, three-way, and double crosses grown at the Pendleton location.

Source	D.F.	Mean Squares Plant height	Tiller number	Harvest Index	Grain yield
Replication	1	550.10	2.18	.0051	9.10
Genotypes	114	57.99**	4.90	.0027	62.96
Error	114	8.17	6.12	.0032	67.26
C.V.		7.60%	10.05%	12.84%	16.80%

**Significant at one percent probability level.

Table 29. Observed mean squares from randomized complete block functional type of analysis of variances for plant height of parents, F_1s and F_2s of single, three-way, and double crosses grown at the Pendleton location.

Source	D.F.	Mean Squares
Replication	1	550.10
Genotypes	114	57.99**
Among Groups	6	49.13
Within Groups[1]	108	58.48**
W/n parents (G_1)	4	151.17**
W/n F_1 S.C. (G_2)	9	102.05**
W/n F_2 S.C. (G_3)	9	105.52**
W/n F_1 3-W. (G_4)	29	56.96**
W/n F_2 3-W. (G_5)	29	49.97**
W/n F_1 D.C. (G_6)	14	24.31*
W/n F_2 D.C. (G_7)	14	28.71**
Rep. x Genotypes[2]	114	8.17
Rep. x Group	6	91.28
Rep. x Group 1[3]	4	1.86
Rep. x Group 2[4]	9	10.55
Rep. x Group 3[5]	9	5.28
Rep. x Group 4[6]	29	1.39
Rep. x Group 5[7]	29	1.67
Rep. x Group 6[8]	14	8.39
Rep. x Group 7[9]	14	1.97

* Significant at five percent probability level.

**Significant at one percent probability level.

[1]Error term for Among Groups.

[2]Error term for Replications, Genotypes, and Within Group.

[3,4,5,6,7,8, and 9]Error term for W/n Group 1,2,3,4,5,6, and 7, respectively.

Table 30. Comparison of the performance for plant height, tiller number, harvest index, and grain yield of five parents grown at the Pendleton location.

Parents	Plant height (cm)	Tiller number	Harvest index	Grain yield (gm/plant)
1. Yamhill	68.03[a*]	22.26	.47	52.90
2. Stephens	75.97[b]	24.80	.49	68.41
3. Daws	71.41[ab]	22.78	.45	42.87
4. Maris Hobbit	65.04[a]	21.40	.45	45.16
5. Druchamp	87.30[c]	18.88	.35	36.61

*Means without and/or with letter in common are not significantly different based on Duncan's New-Multiple Range Test at five percent probability level.

and Daws were intermediate in height (75.97 cm and 71.41 cm respectively).

Actual and Predicted Performance of Single Crosses

The comparison of the performance of single crosses at Pendleton location is given in Table 31.

Among F_1s the cross Yamhill/Daws was the tallest (88.42 cm) but it was not significantly different from the crosses Stephens/Druchamp, Yamhill/Druchamp or Daws/Druchamp. The crosses Maris Hobbit/Druchamp, and Yamhill/Stephens were intermediate in height (79.15 cm, and 79.46 cm, respectively); Stephens/Daws and Daws/Maris Hobbit were shorter (73.07 cm and 74.67 cm respectively). The crosses Stephens/Maris Hobbit, and Yamhill/Maris Hobbit were the shortest (69.58 cm, and 68.28 cm respectively).

Among F_2s, the cross Daws/Druchamp was the tallest (90.46 cm) followed by Yamhill/Druchamp, Maris Hobbit/Druchamp, Stephens/Maris Hobbit, Stephens/Druchamp and Yamhill/Stephens (80.30 cm, 80.96 cm, 82.95 cm and 74.92 cm respectively). The cross Yamhill/Maris Hobbit was the shortest (67.83 cm) but it was not significantly different from that of Daws/Maris Hobbit or Stephens/Daws (70.78 cm and 72.26 cm respectively).

Plant height of F_1 and F_2 on the average was not significantly different.

Table 31. Comparison of the performance, mid-parent, and heterosis values for plant height, tiller number, harvest index, and grain yield for single crosses grown at the Pendleton location.

Performance or value of	Characteristics			
	Plant height (cm)	Tiller number	Harvest index	Grain yield (gm/plant)
Yamhill	68.03	22.26	.47	52.90
Stephens	75.97	24.80	.49	68.41
Mid-parent	72.00	23.53	.48	60.65
Yamhill/Stephens F_1	79.46	19.85	.48	49.30
Heterosis	110.30%	84.36%	100.00%	81.28%
Yamhill/Stephens F_2	74.92	23.28	.49	53.82
Yamhill	68.03	22.26	.47	52.90
Daws	71.41	22.79	.45	42.87
Mid-parent	69.72	22.52	.46	47.88
Yamhill/Daws F_1	88.42	26.28	.46	65.19
Heterosis	126.82%	116.69%	100.00%	136.15%
Yamhill/Daws F_2	83.97	22.41	.45	49.82
Yamhill	68.03	22.26	.47	52.90
Maris Hobbit	65.04	21.40	.45	45.16
Mid-parent	66.53	21.83	.46	49.03
Yamhill/Maris Hobbit F_1	68.28	21.26	.48	52.28
Heterosis	102.63%	97.38%	104.34%	106.62%
Yamhill/Maris Hobbit F_2	67.85	22.37	.48	54.56
Yamhill	68.03	22.26	.47	52.90
Druchamp	87.30	18.18	.35	36.61
Mid-parent	77.66	20.57	.41	44.75
Yamhill/Druchamp F_1	84.29	23.57	.48	51.98
Heterosis	108.53%	114.68%	117.07%	116.15%
Yamhill/Druchamp F_2	80.30	23.19	.42	51.30

Table 31 (continued)

Performance or value of	Characteristics: Plant height (cm)	Tiller number	Harvest index	Grain yield (gm/plant)
Stephens	75.97	24.20	.49	68.41
Daws	71.41	22.79	.45	42.87
Mid-parent	73.69	23.79	.47	55.64
Stephens/Daws F_1	73.07	23.32	.46	50.18
Heterosis	99.15%	98.02%	97.87%	90.18%
Stephens/Daws F_2	72.76	23.89	.46	48.11
Stephens	75.97	24.20	.49	68.41
Maris Hobbit	65.04	21.40	.45	45.16
Mid-parent	70.50	23.10	.47	56.78
Stephens/Maris Hobbit	69.58	23.47	.49	57.64
Heterosis	98.69%	102.77%	104.25%	101.51%
Stephens/Maris Hobbit F_2	82.95	21.17	.41	40.52
Stephens	75.97	24.20	.49	68.41
Druchamp	87.30	18.18	.35	36.61
Mid-parent	81.63	21.49	.42	52.51
Stephens/Druchamp F_1	87.23	20.81	.46	58.34
Heterosis	106.86%	97.74%	109.52%	111.10%
Stephens/Druchamp F_2	82.95	23.60	.41	46.50
Daws	71.41	22.79	.45	42.87
Maris Hobbit	65.04	21.40	.45	42.15
Mid-parent	68.22	22.09	.45	44.01
Daws/Maris Hobbit F_1	74.67	24.63	.49	57.83
Heterosis	109.45%	111.49%	108.89%	131.40%
Daws/Maris Hobbit F_2	70.78	23.90	.44	46.41
Daws	71.41	22.79	.45	42.87
Druchamp	87.30	18.18	.35	36.61

Table 31 (continued)

Performance or Value of	Characteristics: Plant height (cm)	Tiller number	Harvest index	Grain yield (gm/plant)
Mid-parent	97.35	20.48	.40	39.74
Daws/Druchamp F_1	83.07	22.13	.46	50.43
Heterosis	104.69%	108.05%	115.00%	126.89%
Daws/Druchamp F_2	90.46	23.18	.39	39.46
Maris Hobbit	65.04	21.40	.45	45.16
Druchamp	87.30	18.18	.35	36.61
Mid-parent	76.17	19.79	.40	40.88
Maris Hobbit/ Druchamp F_1	79.15	22.16	.39	44.27
Heterosis	103.91%	111.97%	97.50%	108.29%
Maris Hobbit/ Druchamp F_2	80.96	25.37	.39	51.35
Mean of F_1	78.72	22.75	.46	53.74
Mean of F_2	78.79	23.24	.43	48.08
Difference required for significance:				
- Parents	3.79	ns	ns	ns
- Mean of F_1	7.35	ns	ns	ns
- Mean of F_2	5.20	ns	ns	ns
- Mean of F_1 and mean of F_2	ns	ns	ns	ns

ns = No comparison due to nonsignificant difference.

The correlation coefficients between mid-parent value and F_1, mid-parent value and F_2, F_1 and F_2, heterosis estimate and F_2 for plant height are given in Table 32. All relationships except that between the heterosis estimate and F_2 were significantly correlated (correlation coefficients were .63, .65, .64, and .20 respectively).

Actual and Predicted Performance of Three-way Crosses

The performance of F_1 and F_2 of 30 three-way crosses at the Pendleton location are presented in Tables 33 and 34, respectively. Since plant height was significantly different within three-way crosses, further analyses were performed. Table 35 shows the comparison of plant height of the crosses resulting from different parental combinations and different parental orders in F_1 and F_2.

Among F_1s, the combination Yamhill, Daws, Druchamp gave the tallest progenies (86.97 cm), while, combination Yamhill, Stephens, Maris Hobbit gave the shortest progenies (72.47 cm).

Among F_2s, the combination Stephens, Daws, Druchamp and the combination Yamhill, Daws, Druchamp gave the tallest progenies. This was similar to the F_1, where the combination Yamhill, Stephens, Maris Hobbit gave the shortest progenies. No differences between the means of F_1 and F_2 were found. With the exception of the Yamhill, Stephens, Daws combination in the F_1, parental combination order led

Table 32. Correlation coefficients between mid-parent and F_1, mid-parent and F_2, F_1 and F_2, and heterosis and F_2, for plant height of single crosses grown at the Pendleton location.

Correlation between	n	Correlation coefficient
Mid-parent and F_1	10	0.63**
Mid-parent and F_2	10	0.65**
F_1 and F_2	10	0.64**
Heterosis and F_2	10	0.20

**Significant at one percent probability level.

Table 33. Performance of F_1s for plant height, tiller number, harvest index, and grain yield of three-way crosses grown at the Pendleton location.

Crosses	Plant height (cm)	Tiller number	Harvest index	Grain yield (gm/plant)
Yamhill/Stephens//Daws	81.94	23.14	.38	38.40
Yamhill/Stephens//Maris Hobbit	69.10	25.32	.38	43.11
Yamhill/Stephens//Druchamp	79.71	22.93	.42	48.82
Yamhill/Daws//Stephens	80.91	24.67	.41	47.39
Yamhill/Daws//Maris Hobbit	75.39	25.27	.41	50.06
Yamhill/Daws//Druchamp	93.21	26.49	.38	51.66
Yamhill/Maris Hobbit//Stephens	73.83	22.69	.35	70.72
Yamhill/Maris Hobbit//Daws	79.25	23.39	.44	53.11
Yamhill/Maris Hobbit//Druchamp	80.65	21.36	.45	49.92
Yamhill/Druchamp//Stephens	83.87	21.55	.42	45.39
Yamhill/Druchamp//Daws	86.01	21.93	.43	46.02
Yamhill/Druchamp//Maris Hobbit	74.42	21.85	.49	60.19
Stephens/Daws//Yamhill	81.04	23.35	.44	48.61
Stephens/Daws//Maris Hobbit	72.48	23.76	.42	44.16
Stephens/Daws//Druchamp	88.81	25.45	.42	48.14

Table 33 (continued)

Crosses	Plant height (cm)	Tiller number	Harvest index	Grain yield (gm/plant)
Stephens/Maris Hobbit//Yamhill	74.49	20.88	.46	45.37
Stephens/Maris Hobbit//Daws	73.96	25.57	.43	47.32
Stephens/Maris Hobbit//Druchamp	83.77	25.16	.41	52.80
Stephens/Druchamp//Yamhill	76.06	21.80	.43	45.86
Stephens/Druchamp//Daws	83.57	24.80	.49	56.53
Stephens/Druchamp//Maris Hobbit	75.86	21.15	.43	46.10
Daws/Druchamp//Yamhill	81.69	21.66	.49	55.15
Daws/Druchamp//Stephens	74.93	19.85	.49	48.37
Daws/Druchamp//Maris Hobbit	72.82	23.14	.41	45.43
Daws/Maris Hobbit//Yamhill	74.99	20.59	.52	53.82
Daws/Maris Hobbit//Stephens	75.34	23.65	.42	45.84
Daws/Maris Hobbit//Druchamp	82.04	25.41	.42	52.33
Maris Hobbit/Druchamp//Yamhill	75.07	23.02	.45	55.65
Maris Hobbit/Druchamp//Stephens	76.14	24.23	.49	58.35
Maris Hobbit/Druchamp//Daws	80.97	22.38	.47	48.45
Difference required for significance	2.41	ns	ns	ns

ns = No comparison due to nonsignificant difference.

Table 34. Performance of F_2s for plant height, tiller number, harvest index, and grain yield of three-way crosses grown at the Pendleton location.

Crosses	Plant height (cm)	Tiller number	Harvest index	Grain yield (gm/plant)
Yamhill/Stephens//Daws	82.41	26.87	.43	51.06
Yamhill/Stephens//Maris Hobbit	68.13	24.30	.44	48.90
Yamhill/Stephens//Druchamp	83.41	23.43	.40	43.91
Yamhill/Daws//Stephens	77.85	24.66	.48	51.04
Yamhill/Daws//Maris Hobbit	68.69	23.84	.41	40.73
Yamhill/Daws//Druchamp	80.87	23.63	.46	50.82
Yamhill/Maris Hobbit//Stephens	70.72	22.41	.44	44.58
Yamhill/Maris Hobbit//Daws	74.31	21.76	.45	44.29
Yamhill/Maris Hobbit//Druchamp	78.49	23.26	.45	47.55
Yamhill/Druchamp//Stephens	80.29	24.68	.42	49.37
Yamhill/Druchamp//Daws	80.06	24.83	.46	50.01
Yamhill/Druchamp//Maris Hobbit	74.64	21.53	.42	42.94
Stephens/Daws//Yamhill	79.02	23.67	.38	41.79
Stephens/Daws//Maris Hobbit	71.59	23.61	.41	42.78
Stephens/Daws//Druchamp	84.68	22.90	.39	42.32

Table 34 (continued)

Crosses	Plant height (cm)	Tiller number	Harvest index	Grain yield (gm/plant)
Stephens/Maris Hobbit//Yamhill	72.14	23.21	.47	51.57
Stephens/Maris Hobbit//Daws	77.77	26.28	.39	41.11
Stephens/Maris Hobbit//Druchamp	77.71	25.73	.40	46.69
Stephens/Druchamp//Yamhill	76.33	21.08	.48	52.03
Stephens/Druchamp//Daws	83.16	24.69	.42	42.20
Stephens/Druchamp//Maris Hobbit	71.99	24.30	.46	51.85
Daws/Druchamp//Yamhill	86.40	23.26	.41	43.44
Daws/Druchamp//Stephens	82.09	25.34	.39	40.19
Daws/Druchamp//Maris Hobbit	77.14	24.10	.41	41.99
Daws/Maris Hobbit//Yamhill	80.66	24.72	.47	53.01
Daws/Maris Hobbit//Stephens	74.35	26.89	.42	44.83
Daws/Maris Hobbit//Druchamp	84.99	24.87	.39	47.53
Maris Hobbit/Druchamp//Yamhill	73.68	21.73	.36	37.16
Maris Hobbit/Druchamp//Stephens	74.88	22.98	.42	42.30
Maris Hobbit/Druchamp//Daws	74.83	23.38	.38	34.73
Difference required for significance	2.64	ns	ns	ns

ns = No comparison due to nonsignificant difference.

Table 35. Comparison of plant heights (cm) for F_1 and F_2 resulting from different parental combinations and different parental orders of three-way crosses grown at the Pendleton location.

Combinations and Orders of Crosses	F_1	F_2
Parents combined: Yamhill, Stephens, Daws		
Yamhill/Stephens//Daws	81.94	82.41
Yamhill/Daws//Stephens	80.91	77.85
Stephens/Daws//Yamhill	81.04	79.02
Mean	81.30	79.76
Parents combined: Yamhill, Stephens, Maris Hobbit		
Yamhill/Stephens//Maris Hobbit	69.10	68.13
Yamhill/Maris Hobbit//Stephens	73.83	70.72
Stephens/Maris Hobbit//Yamhill	74.49	72.14
Mean	72.47	70.33
Parents combined: Yamhill, Stephens, Druchamp		
Yamhill/Stephens//Druchamp	79.71	83.41
Yamhill/Druchamp//Stephens	83.87	80.29
Stephens/Druchamp//Yamhill	76.06	76.33
Mean	79.88	80.01
Parents combined: Yamhill, Daws, Maris Hobbit		
Yamhill/Daws//Maris Hobbit	75.39	68.69
Yamhill/Maris Hobbit//Daws	79.25	74.31
Daws/Maris Hobbit//Yamhill	74.99	80.66
Mean	76.54	74.55
Parents combined: Yamhill, Daws, Druchamp		
Yamhill/Daws//Druchamp	93.21	80.87
Yamhill/Druchamp//Daws	86.01	80.06
Daws/Druchamp//Yamhill	81.69	86.40
Mean	86.97	82.44
Parents combined: Stephens, Daws, Maris Hobbit		
Stephens/Daws//Maris Hobbit	72.48	71.59
Stephens/Maris Hobbit//Daws	73.96	77.77
Daws/Maris Hobbit//Stephens	75.34	74.35
Mean	73.93	74.57
Parents combined: Stephens, Daws, Druchamp		
Stephens/Daws//Druchamp	88.81	84.68
Stephens/Druchamp//Daws	83.57	83.16
Daws/Druchamp//Stephens	74.93	82.09
Mean	82.44	83.31

Table 35 (continued)

Combinations and Orders of Crosses	F_1	F_2
Parents combined: Yamhill, Maris Hobbit, Druchamp		
Yamhill/Maris Hobbit//Druchamp	80.65	78.49
Yamhill/Druchamp//Maris Hobbit	74.42	74.64
Maris Hobbit/Druchamp//Yamhill	75.07	73.68
Mean	76.71	75.60
Parents combined: Stephens, Maris Hobbit, Druchamp		
Stephens/Maris Hobbit//Druchamp	83.77	77.71
Stephens/Druchamp//Maris Hobbit	75.86	71.99
Maris Hobbit/Druchamp//Stephens	76.14	74.88
Mean	78.59	74.86
Parents combined: Daws, Maris Hobbit, Druchamp		
Daws/Maris Hobbit//Druchamp	82.04	84.99
Daws/Druchamp//Maris Hobbit	72.82	77.14
Maris Hobbit/Druchamp//Daws	80.97	74.83
Mean	78.61	78.98
Difference required for significance		
- Combination mean	1.39	1.52
- Order of crosses	2.41	2.64

to significant differences in plant height in all cases in both generations. Even in the excepted case, the top cross parent was important.

Actual and predicted plant heights for three-way crosses at the Pendleton location are presented in Table 36. Correlation coefficients between actual and predicted values of both predicting models were high and significant. Model II showed higher r values (Model I: r = .66 for F_1 and r = .69 for F_2, Model II: r = .76 for F_1 and r = .81 for F_2).

Actual and Predicted Performance of Double Crosses

The performance of fifteen double crosses at the Pendleton location are given in Table 37. Since plant height was different significantly in both F_1 and F_2, the trait was compared between different parental combinations and between different orders of combination (Table 38).

Among F_1's, combination Yamhill, Stephens, Daws, Druchamp gave the tallest progenies (83.27 cm); however the mean height was not significantly different from that of the combination Yamhill, Daws, Maris Hobbit, Druchamp. No significant difference was observed among the other three combinations. Significant differences were not found when different orders of combination were compared in the F_1.

In both generations, the combination Yamhill, Daws, Maris Hobbit, Stephens gave the shortest progenies and

Table 36. Actual and predicted plant heights (cm) of three-way crosses grown at the Pendleton location.

Crosses	Predicted Values Model I	Model II	Actual Values F_1	F_2
Yamhill/Stephens//Daws	71.70	80.74	81.94	82.41
Yamhill/Stephens//Maris Hobbit	68.52	68.93	69.10	68.13
Yamhill/Stephens//Druchamp	79.65	85.76	79.71	83.41
Yamhill/Daws//Stephens	72.84	76.26	80.91	77.85
Yamhill/Daws//Maris Hobbit	67.38	71.47	75.39	68.69
Yamhill/Daws//Druchamp	78.51	83.68	93.21	80.87
Yamhill/Maris Hobbit//Stephens	71.21	74.52	73.83	70.72
Yamhill/Maris Hobbit//Daws	68.97	81.54	79.25	74.31
Yamhill/Maris Hobbit//Druchamp	76.91	81.72	80.65	78.49
Yamhill/Druchamp//Stephens	76.81	83.34	83.87	80.29
Yamhill/Druchamp//Daws	74.54	85.74	86.01	80.06
Yamhill/Druchamp//Maris Hobbit	71.35	73.71	74.42	74.64
Stephens/Daws//Yamhill	70.85	83.94	81.04	79.02
Stephens/Daws//Maris Hobbit	69.36	72.12	72.48	71.54
Stephens/Daws//Druchamp	80.49	85.15	88.81	84.68
Stephens/Maris Hobbit//Yamhill	67.28	73.87	74.49	72.14
Stephens/Maris Hobbit//Daws	68.97	73.87	73.96	72.77
Stephens/Maris Hobbit//Druchamp	76.92	83.19	83.77	77.71
Stephens/Druchamp//Yamhill	74.83	81.78	76.06	76.33
Stephens/Druchamp//Daws	76.52	78.07	83.57	83.16
Stephens/Druchamp//Maris Hobbit	73.33	74.33	75.86	71.99
Daws/Druchamp//Yamhill	73.69	86.35	81.69	86.40
Daws/Druchamp//Stephens	77.66	80.15	74.93	82.09
Daws/Druchamp//Maris Hobbit	72.20	76.91	72.82	77.14
Daws/Maris Hobbit//Yamhill	68.13	78.35	74.99	80.66
Daws/Maris Hobbit//Stephens	72.10	71.32	75.34	74.35
Daws/Maris Hobbit//Druchamp	77.76	81.88	82.04	84.99
Maris Hobbit/Druchamp//Yamhill	72.10	76.28	75.07	73.68
Maris Hobbit/Druchamp//Stephens	76.07	78.40	76.14	74.88
Maris Hobbit/Druchamp//Daws	73.79	78.87	80.79	74.83
Correlation coefficient for Model I			0.66**	0.69**
Correlation coefficient for Model II			0.76**	0.81**

**Significant at one percent probability level.

Table 37. Performance of F_1 and F_2 for plant height, tiller number, harvest index and grain yield of double crosses grown at the Pendleton location.

Crosses	F_1 Plant height (cm)	F_1 Tiller number	F_1 Harvest index	F_1 Grain yield (gm/plant)	F_2 Plant height (cm)	F_2 Tiller number	F_2 Harvest index	F_2 Grain yield (gm/plant)
Yamhill/Stephens//Daws/Maris Hobbit	76.12	23.38	.34	38.99	69.98	21.14	.46	46.33
Yamhill/Stephens//Daws/Druchamp	82.67	22.94	.40	43.00	80.53	22.85	.48	51.97
Yamhill/Stephens//Maris Hobbit/Druchamp	76.19	22.39	.41	43.60	77.09	23.15	.41	45.66
Yamhill/Daws//Stephens/Maris Hobbit	75.43	21.28	.44	44.50	74.01	23.71	.49	51.99
Yamhill/Daws//Stephens/Druchamp	85.20	23.03	.38	42.13	84.27	25.64	.43	48.49
Yamhill/Daws//Maris Hobbit/Druchamp	80.14	22.47	.48	56.35	80.98	24.26	.44	51.21
Yamhill/Maris Hobbit//Stephens/Daws	72.64	20.45	.46	45.77	73.84	23.91	.48	49.94
Yamhill/Maris Hobbit//Stephens/Druchamp	75.36	23.29	.48	54.94	80.44	22.85	.41	44.88
Yamhill/Maris Hobbit//Daws/Druchamp	82.95	24.22	.45	50.51	78.52	24.26	.47	55.04
Yamhill/Druchamp//Stephens/Daws	81.94	22.47	.41	39.76	81.33	24.26	.43	48.82
Yamhill/Druchamp//Stephens/Maris Hobbit	77.44	23.18	.45	50.61	78.61	24.65	.46	51.91
Yamhill/Druchamp//Daws/Maris Hobbit	81.02	22.31	.47	50.44	81.67	26.32	.45	53.88
Stephens/Daws//Maris Hobbit/Druchamp	77.63	22.53	.43	42.61	75.59	22.81	.46	44.45
Stephens/Maris Hobbit//Daws/Druchamp	77.56	23.34	.46	48.77	81.68	24.21	.43	43.22
Stephens/Druchamp//Daws/Maris Hobbit	77.86	22.88	.41	44.39	77.63	24.05	.40	39.72
Difference required for significance	6.21	ns	ns	ns	3.01	ns	ns	ns

ns = No comparison due to nonsignificant difference.

Table 38. Comparison of plant heights (cm) of F_1 and F_2 resulting from different parental combinations and different parental orders of double crosses grown at the Pendleton location.

Combinations and Order of Crosses	F_1	F_2
Parents combined: Yamhill, Stephens, Daws, Maris Hobbit		
Yamhill/Stephens//Daws/Maris Hobbit	76.12	69.98
Yamhill/Daws//Stephens/Maris Hobbit	75.43	74.01
Yamhill/Maris Hobbit//Stephens/Daws	72.64	73.84
Mean	74.73	72.61
Parents combined: Yamhill, Stephens, Daws, Druchamp		
Yamhill/Stephens//Daws/Druchamp	82.67	80.52
Yamhill/Daws//Stephens/Druchamp	85.20	84.27
Yamhill/Druchamp//Stephens/Daws	81.94	81.33
Mean	83.27	82.04
Parents combined: Yamhill, Stephens, Maris Hobbit, Druchamp		
Yamhill/Stephens//Maris Hobbit/Druchamp	76.19	77.09
Yamhill/Maris Hobbit//Stephens/Druchamp	72.64	73.84
Yamhill/Druchamp//Stephens/Maris Hobbit	77.44	78.61
Mean	75.42	76.78
Parents combined: Yamhill, Daws, Maris Hobbit, Druchamp		
Yamhill/Daws//Maris Hobbit/Druchamp	80.14	80.98
Yamhill/Maris Hobbit//Daws/Druchamp	82.95	78.52
Yamhill/Druchamp//Daws/Maris Hobbit	81.02	81.67
Mean	81.37	80.39
Parents combined: Stephens, Daws, Maris Hobbit, Druchamp		
Stephens/Daws//Maris Hobbit/Druchamp	77.63	75.59
Stephens/Maris Hobbit//Daws/Druchamp	77.65	81.68
Stephens/Druchamp//Daws/Maris Hobbit	77.86	77.63
Mean	77.13	78.30
Difference required for significance		
- Combination mean	3.59	1.74
- Order of crosses	6.21	3.01

Yamhill, Stephens, Daws, Druchamp gave the tallest. Differences among orders within combinations were found in all cases in F_2.

Actual and predicted plant height in double crosses given by three predicting models are given in Table 39. All three models gave significantly high correlation coefficients between the actual and predicted values. Model I however, gave higher r values than Model II and Model III for both generations (Model I: r = .90 for F_1 and r = .80 for F_2, Model II: r = .69 for F_1 and r = .62 for F_2, Model III: r = .58 for F_1 and r = .74 for F_2).

Combined Analysis of Both Locations

Genotype x Environment Interaction

Observed mean squares from a combined analysis of variance of the data from Hyslop and Pendleton locations are given in Table 40. Genotypes were significantly different for plant height and grain yield across locations but not significantly different for tiller number or harvest index. Genotype x environment (location) interaction for plant height was found to be significant, while nonsignificant differences were found for the other traits. Observed mean squares of the analysis of variance for parents are given in Table 41. Both genotypes and the location x genotype interaction were significant. The comparison of plant heights of five parents across locations is shown in Table

Table 39. Actual and predicted plant heights (cm) of double crosses grown at the Pendleton location.

Crosses	Predicted Values			Actual Values	
	Model I	Model II	Model III	F_1	F_2
Yamhill/Stephens//Daws/Maris Hobbit	75.58	74.83	70.11	76.11	69.98
Yamhill/Stephens//Daws/Druchamp	82.59	83.25	75.68	82.67	80.52
Yamhill/Stephens//Maris Hobbit/Druchamp	78.00	77.34	74.08	76.19	77.09
Yamhill/Daws//Stephens/Maris Hobbit	75.58	73.87	70.11	75.43	74.01
Yamhill/Daws//Stephens/Druchamp	82.59	79.97	75.68	85.20	84.27
Yamhill/Daws//Maris Hobbit/Druchamp	79.64	77.58	72.94	80.14	80.98
Yamhill/Maris Hobbit//Stephens/Daws	75.58	78.03	70.11	72.64	73.84
Yamhill/Maris Hobbit//Stephens/Druchamp	78.00	78.12	74.08	75.36	80.44
Yamhill/Maris Hobbit//Daws/Druchamp	79.64	81.63	72.94	82.95	78.52
Yamhill/Druchamp//Stephens/Daws	82.59	84.54	75.68	81.94	81.33
Yamhill/Druchamp//Stephens/Maris Hobbit	78.00	78.53	74.08	74.44	78.61
Yamhill/Druchamp//Daws/Maris Hobbit	79.64	79.73	72.94	81.02	81.69
Stephens/Daws//Maris Hobbit/Druchamp	77.79	78.63	74.93	77.63	75.59
Stephens/Maris Hobbit//Daws/Druchamp	77.79	78.53	74.93	77.65	81.68
Stephens/Druchamp//Daws/Maris Hobbit	77.79	76.21	74.93	77.86	77.63
Correlation coefficient for Model I				0.90**	0.80**
Correlation coefficient for Model II				0.69**	0.62**
Correlation coefficient for Model III				0.58**	0.74**

**Significant at one percent probability level.

Table 40. Observed mean squares from randomized complete block combined analysis of variances for plant height, tiller number, harvest index, and grain yield, for parents, F_1s and F_2s of single, three-way, and double crosses grown at the Hyslop and Pendleton locations.

Source	D.F.	Mean Squares: Plant height	Tiller number	Harvest Index	Grain yield
Location	1	54137.80**	543.50**	0.1278**	6222.80**
Error a	2	311.05	1.37	0.0225	309.60
Genotypes	114	137.19**	5.06	0.0021	61.92**
Location x Genotypes	114	14.37**	4.27	0.0013	46.48
Error b	228	7.15	4.02	0.0016	43.28
Total	459				
C.V.		14.26%	10.54%	10.09%	22.86%

**Significant at one percent probability level.

Table 41. Observed mean squares from combined analysis of variances for plant heights of five parents grown at the Hyslop and Pendleton locations.

Source	D.F.	Mean Squares
Location	1	2441.61
Error a	2	27.24
Genotypes	4	382.97**
Location x Genotypes	4	21.64**
Error b	4	1.55

**Significant at one percent probability level.

42. Stephens, Daws, Maris Hobbit, and Druchamp performed relatively the same in both environments, Druchamp was the tallest with Maris Hobbit being the shortest, Stephens and Daws were intermediate at both locations. Yamhill on the other hand, responded differently in relation to other parents when grown under two different environments. At the Hyslop location Yamhill was a mid-tall parent (rank 2) but it was one of the shortest parents (rank 4) at the Pendleton location.

Comparison of Yield Responses across Locations

The comparison of grain yield (gm/plant) produced by single, three-way, and double crosses for F_1 and F_2 averaged across the Hyslop and Pendleton locations is shown in Table 43.

For F_1s, single crosses produced significantly higher grain yield than three-way crosses but they were not significantly different from that of double crosses. No differences were found between three-way and double crosses for grain yield.

For F_2s, no significant difference among three types of crosses in grain yield was found.

The comparison of the number of high yielding crosses generated by single, three-way, and double crosses averaged across the two locations is presented in Table 44.

Table 42. Comparison of plant heights for five parents grown at the Hyslop and Pendleton locations.

Parents	Hyslop (cm)	Rank	Pendleton (cm)	Rank	Differences between locations (cm)
1. Yamhill	95.95	2	68.03	4	27.92
2. Stephens	95.34	3	75.97	2	19.37
3. Daws	86.40	4	71.41	3	14.99
4. Maris Hobbit	80.93	5	65.04	5	14.89
5. Druchamp	112.58	1	87.30	1	25.28

Table 43. Comparison of grain yield production for single, three-way, and double crosses averaged across the Hyslop and Pendleton locations.

Crosses	Grain Yield (gm per plant) F_1	F_2
Single Crosses	65.25[a*]	59.16
Three-way Crosses	58.81[b]	56.74
Double Crosses	61.22[ab]	58.05

*Means without and/or with letter in common are not significantly different based on Duncan's New-Multiple Range Test at five percent probability level.

Table 44. Comparison of the number of high yielding crosses generated by single, three-way, and double crosses averaged across the Hyslop and Pendleton locations.

Crosses	Number of crosses made	Percentage Number of Crosses: Exceeded the parental mean F_1	Exceeded the parental mean F_2	Exceeded the best parent F_1	Exceeded the best parent F_2
Single crosses	10	100	60	50	10
Three-way crosses	30	66	16	20	none
Double crosses	15	60	40	40	none

For single crosses, all crosses gave higher grain yield than the average of the five parents in F_1 but only 60% of the crosses were higher in the F_2. The percentage of crosses exceeding the highest parent were 50% and 10% in F_1 and F_2 respectively.

For three-way crosses, 66% of the crosses gave higher grain yield than the average of the five parents in F_1 while only 16% of them did so in F_2. Twenty percent of the crosses outyielded the highest parent in F_1. This was reduced to zero in the F_2 as none of the crosses were superior to the highest parent.

For double crosses, 60% and 40% of the crosses produced higher grain yield than the average of the parents in F_1 and F_2, respectively. Forty percent of the crosses outyielded the best parent in F_1 but non did so in F_2.

Comparison of the Magnitudes of Genetic Variances

Genetic variability in F_2 of single crosses for plant height and grain yield across locations is given in Table 45. The crosses Daws/Druchamp, Stephens/Daws, and Yamhill/Stephens generated greater genetic variability for plant height. The crosses Yamhill/Stephens and Yamhill/Druchamp created more genetic variability for grain yield.

Genetic variability in three-way crosses for plant height, and grain yield is presented in Table 46. No genetic variability could be detected in the F_1 for either

Table 45. Magnitudes of genetic variances generated in the F_2 of single crosses for plant height, and grain yield across the Hyslop and Pendleton locations.

Crosses	Plant height	Grain yield
Yamhill/Stephens	121.56	40.29
Yamhill/Daws	94.61	-[a]
Yamhill/Maris Hobbit	-	-
Yamhill/Druchamp	-	48.57
Stephens/Daws	179.14	-
Stephens/Maris Hobbit	75.61	14.84
Stephens/Druchamp	15.55	2.46
Daws/Maris Hobbit	-	-
Daws/Druchamp	167.49	-
Maris Hobbit/Druchamp	-	-
Average	65.39	10.61

[a]Undetectable amount

Table 46. Magnitudes of genetic variances generated in the F_2 of three-way crosses for plant height, and grain yield, across the Hyslop and Pendleton locations.

Crosses	Plant height	Grain yield
Yamhill/Stephens//Daws	119.82	19.63
Yamhill/Stephens//Maris Hobbit	24.22	10.57
Yamhill/Stephens//Druchamp	1.64	-[a]
Yamhill/Daws//Stephens	103.50	16.90
Yamhill/Daws//Maris Hobbit	6.14	-
Yamhill/Daws//Druchamp	47.08	123.31
Yamhill/Maris Hobbit//Stephens	14.74	-
Yamhill/Maris Hobbit//Daws	55.70	46.11
Yamhill/Maris Hobbit//Druchamp	-	50.80
Yamhill/Druchamp//Stephens	-	53.77
Yamhill/Druchamp//Daws	77.59	-
Yamhill/Druchamp//Maris Hobbit	-	17.21
Stephens/Daws//Yamhill	14.03	-
Stephens/Daws//Maris Hobbit	20.58	166.70
Stephens/Daws//Druchamp	57.95	-
Stephens/Maris Hobbit//Yamhill	23.65	48.03
Stephens/Maris Hobbit//Daws	145.07	68.25
Stephens/Maris Hobbit//Druchamp	20.57	10.14
Stephens/Druchamp//Yamhill	-	133.74
Stephens/Druchamp//Daws	80.22	74.32
Stephens/Druchamp//Maris Hobbit	8.19	138.72
Daws/Druchamp//Yamhill	-	23.74
Daws/Druchamp//Stephens	106.98	40.11
Daws/Druchamp//Maris Hobbit	-	-
Daws/Maris Hobbit//Yamhill	6.17	72.58
Daws/Maris Hobbit//Stephens	122.77	23.08
Daws/Maris Hobbit//Druchamp	10.67	9.60
Maris Hobbit/Druchamp//Yamhill	-	22.10
Maris Hobbit/Druchamp//Stephens	12.76	-
Maris Hobbit/Druchamp//Daws	21.41	-
Average	36.72	38.99

[a]Undetectable amount.

trait. In F_2, the cross Stephens/Maris Hobbit//Daws resulted in greater genetic variability for plant height. The crosses Stephens/Daws//Maris Hobbit generated greater genetic variability for grain yield. It should be noted that the combination Stephens, Daws, Maris Hobbit was also the highest yielding combination in the F_1 at the Hyslop location.

Among double crosses, genetic variability generated by different crosses is provided in Table 47. Genetic variability among F_1 plants within each double cross in general was greater than that of F_2 in both traits. For plant height the cross Stephens/Maris Hobbit//Daws/Druchamp resulted in greater genetic variability in F_1 (150.13). The cross Yamhill/Maris Hobbit//Stephens/Daws created greater genetic variability in F_2 for plant height (149.19). For grain yield the cross Yamhill/Maris Hobbit//Stephens/Druchamp produced the greatest amount of genetic variability in F_1, while the cross Yamhill/Maris Hobbit//Stephens/Daws gave higher genetic variability in F_2.

The magnitude of genetic variability for plant height on the average was highest for double crosses followed by single crosses with three-way crosses being lowest. For grain yield the double crosses generated the greatest genetic variability followed by the three-way, and then the single crosses.

Table 47. Magnitudes of genetic variances generated in F_1, and F_2 generations of double crosses for plant height, and grain yield across the Hyslop and Pendleton locations.

Crosses	F_1 Plant height	F_1 Grain yield	F_2 Plant height	F_2 Grain yield
Yamhill/Stephens//Daws/Maris Hobbit	79.38	15.92	63.25	15.09
Yamhill/Stephens//Daws/Druchamp	127.05	76.77	94.10	27.62
Yamhill/Stephens//Maris Hobbit/Druchamp	57.54	135.35	20.80	-[a]
Yamhill/Daws//Stephens/Maris Hobbit	147.56	121.25	91.10	-
Yamhill/Daws//Stephens/Druchamp	123.47	-	28.76	-
Yamhill/Daws//Maris Hobbit/Druchamp	144.07	142.55	9.31	-
Yamhill/Maris Hobbit//Stephens/Daws	113.86	125.89	66.60	111.52
Yamhill/Maris Hobbit//Stephens/Druchamp	72.37	189.37	18.82	-
Yamhill/Maris Hobbit//Daws/Druchamp	108.23	79.33	46.03	-
Yamhill/Druchamp//Stephens/Daws	82.38	104.80	149.19	-
Yamhill/Druchamp//Stephens//Maris Hobbit	91.96	99.94	-	-
Yamhill/Druchamp//Daws/Maris Hobbit	41.11	116.52	-	29.26
Stephens/Daws//Maris Hobbit/Druchamp	139.20	-	17.42	-
Stephens/Maris Hobbit//Daws/Druchamp	150.13	67.77	42.22	-
Stephens/Druchamp//Daws/Maris Hobbit	142.63	29.82	102.96	-
Average	109.39	87.01	50.03	12.23

[a] Undetectable amount.

DISCUSSION

Increasing wheat production per hectare through the development of superior yielding cultivars has contributed significantly to the world's food supply. Perhaps the best known example was the development of day-length insensitive semi-dwarf cultivars by the International Maize and Wheat Improvement Center in Mexico. However, with the development of spring type wheat cultivars such as 'Anza', and 'Siete Cerros' in Mexico and winter types such as 'Gaines', 'Centurk' and 'Hyslop' in the United States, concerns are being expressed regarding possible yield plateaus. More recently released wheat cultivars reflect progress in disease or insect resistance and greater straw strength rather than in grain yield per se. If wheat is going to continue to be a major food source it will not only be necessary for breeders to become more efficient in identifying more durable sources of disease and insect resistance, but cultivars with higher and more stable grain yielding capacity must also be developed. This efficiency could be greatly enhanced if the plant breeder had a means of identifying those parental combinations which would result in the highest percentage of desirable plants in segregating populations. With over 35,000 wheat cultivars in the United States Department of Agriculture world collection and available to breeders for hybridization, the task of parental identification has been difficult.

For simply inherited traits such as those controlled by major genes, selection of parental combinations for crossing is obvious. A much different situation exists for quantitatively inherited traits like yield where the inheritance and the final expression are greatly influenced by many environmental factors. Here the choice of parental combinations is usually by trial and error. There is also a tendency when favorable combinations are found to use them extensively thus narrowing the genetic diversity between cultivars. This in turn can result in greater disease and insect problems and can limit yield potential and yield stability.

Choice of Breeding Approaches

Associated with the choice of parental combinations in normally self-pollinated species is the breeding approach. Two major breeding approaches are 1) conventional methods of breeding and selection, and 2) the use of hybrids. In the conventional breeding procedure in self-pollinated species, such as wheat the steps involved 1) hybridizing genetically dissimilar parents to create genetic variability, 2) artifically or through natural selection, identifying the desirable segregates, and 3) selfing, multiplying and releasing the most promising selections as new cultivars. In this approach only the additive portion of total genetic variance can be utilized or fixed due to the loss of heterozygosity with selfing. This is in contrast to the hybrid breeding approach where the F_1 population is used in commercial production. Therefore the total genetic variance involving both additive and nonadditive portions can be used. The choice of the most promising parental combinations may change depending on the breeding approach. This investigation concentrated on (1) providing a guideline in identifying the most promising parental combinations for both conventional and hybrid breeding approaches, (2) determining if the sequence in which parents are used in multiple crosses is important, and (3) evaluating the relative merits of single, three-way, and double crosses in terms of increasing usable genetic diversity.

Choice of Parents

Most wheat breeders currently tend to make crosses between high yielding cultivars with the hope that in doing so there is a greater chance of combining more favorable genes. This has been quite successful, particularly in the breeding programs where resources permit the evaluation of many crosses and large populations. However, such resources are not always available, especially in most of the developing countries. Breeders therefore have relied on their own personal experience and that of other researchers. Regarding the choice of the promising parents in hybrid corn, Rinkle and Hayes (1964) reported that the inbred lines which had high general combining ability (GCA) tend to produce higher yields in single crosses. In wheat, Kronstad and Foote (1964) pointed out that combining ability analysis is useful in selecting possible potential parents for hybridization. Peterson et al. (1969) suggested that the best parents for the development of hybrid wheat were those with high GCA effects. In light of these findings, the results from this study were particularly interesting regarding the choice of parents based on combining ability for single, three-way, and double crosses. The cross combination with the highest total GCA (sum of the general combining ability effects of parents involved) for a given trait resulted in progeny with a high population mean. This was true for all measured characters in both F_1 and F_2 generations. Therefore GCA of the cultivar appears to be a useful statistic in selecting the most promising parental combinations.

Choice of Type of Crosses

In the past most breeding programs emphasized the use of single crosses. More recently three-way, and double crosses are receiving more attention especially in conventional breeding programs. There is limited information available regarding the relative merits of these three types of crosses. Studies conducted by Potocanac and Engelman (1968) in wheat suggested that three-way crosses gave progeny with a higher percentage of short straw, high fertility per spike and resistance to stem rust than single crosses. Studies in grain sorghum by Jowell (1972), and Otasuka et al. (1974) suggested that the mean grain yield of single cross hybrids did not significantly differ from that of three-way hybrids, but three-way hybrid had greater yield stability over a range of environments. Three-way hybrids also provided greater variability for plant height and maturity than single crosses. Similar findings were pointed out by Patanothai et al. (1974). The variability for maturity in three-way hybrids however, did not seem large enough to cause problems at harvest as reported by Atkin (1973), and Stephens and Larh (1973). Very little information is available regarding the relative performance of single, three-way, and double crosses in wheat.

Theoretically the making of three-way, and double crosses are to bring together the genetic materials from several promising sources, thus enhancing the opportunity of obtaining more usable genetic variability in the resulting segregating populations. The results obtained in this study were in agreement with the theoretical expectations.

For F_1 grain yield, no significant difference was found between single and double crosses, however the grain yield of three-way crosses was significantly lower. In the

F_2 however, no significant difference between the grain yield of the three types of crosses was found. Segregation in the F_1 generation of three-way, and double crosses resulted in some inbreeding depression. Population sizes were not adequate enough to recover all of the potential segregates which might also explain the failure of three-way or double crosses to outyield the single crosses in this generation.

In this study three-way and double crosses generated more genetic variability than single crosses for the traits studied. A conventional breeding program should emphasize three-way or double crosses, while in the production of hybrid wheat, single crosses and double crosses should be recommended based on the magnitude of genetic variability generated.

Prediction of Crosses Performance

As previously noted, with the large number of potential parents available, the choice of possible cross combinations is frequently difficult especially for quantitatively inherited traits. If plant breeders could predict the performance of the progeny resulting from a cross before any crosses are actually made, time and expenses would be decreased, thus resulting in greater efficiency in developing a new cultivar.

Breeders in cross-pollinated crops such as corn have used the prediction methods of parental evaluation for the production of commercial hybrids since 1932. Unfortunately this sort of information is very limited in self-pollinated crops.

In single crosses, mid-parent values were found to be very good predictors of the resulting performance of F_1 and F_2 for plant height, tiller number, and harvest index. Therefore mid-parent values are very helpful in selecting the appropriate cross combinations for the desirable plant height, tiller number, and harvest index. Moreover the F_1 and heterosis estimate also gave high correlation coefficients with the F_2 for these traits. Implications of these results are that after some crosses have been made on the basis of mid-parent values, the performance of the F_1 as well as the heterosis estimate could serve as a double check in predicting the F_2 plant height, tiller number, and harvest index. Therefore for simply inherited traits, the breeder could predict the performance of the resulting progeny of a cross by using the mid-parent value, or F_1 performance or heterosis estimate. However, none of these statistics proved useful in predicting grain yield. The results from this study were in agreement with the information reported by Fowlew et al. (1955) who found that the parent values were useful in predicting plant height and maturity, but not yield in winter wheat.

Among the 30 different three-way crosses, significant differences in grain yield were found in F_1s, while no significant difference for this trait was found in any other case. It would seem that the order in which the parents are combined in a three-way cross is important, since the five parents used were not significantly different for grain yield. The top cross parent in a three-way cross had more influence upon the progeny than the parents in the original single cross. This effect was more pronounced where the top cross parent had a low GCA for a specific trait. These results supported the finding of Harrington (1952), and Potocanac <u>et al</u>. (1968). Therefore the choice of the top cross parent with a high GCA value for the trait involved is critical for success in three-way crosses.

Of the two models used to predict the performance of three-way crosses, only additive genetic effects were taken into consideration in Model I. In Model II, both additive and nonadditive genetic variances are important. Theoretically with traits which are influenced mainly by additive gene action, Model I should be more appropriate than Model II; while in predicting those traits where both additive and nonadditive genetic variances are important, Model II should be more appropriate than Model I. The results in this study agreed with the theoretical expectations. For plant height and harvest index where both additive and nonadditive gene action were important, Model II gave higher r values between actual and predicted performance than Model I. For tiller number where additive gene action was predominant, Model I gave the better estimate. When the nature of gene action governing the traits is known, the application of a predicting model can be of more value.

Grain yields of 15 double crosses were not significantly different, therefore the importance of order in the composition of the double cross was negligible. For plant height, tiller number, and harvest index however, the order in which parents were combined was important. For plant height, the order in the combination of Yamhill, Stephens, Maris hobbit and Druchamp did make a difference. Yamhill and Druchamp were mid-tall while Stephens and Maris Hobbit were semi-dwarf cultivars at the Hyslop location. The cross Yamhill/Druchamp//Maris Hobbit/Stephens gave significantly shorter progenies than the two other possible crossing orders. The same phenomenon was found in the F_2 for tiller number. The crosses low/low//high/high tillering parents gave the lowest tillering progenies on the average. The study conducted by Eckhardt and Bryan (1940) showed that in hybrid corn, the highest yielding double cross will most likely be derived from two single crosses involving four different varieties. For more uniformity in maturity they recommend to use the order early/early//late/late. To obtain more genetic variability for a given trait the opposite way of combining the parents might be suggested.

As noted by data in Table 47, the cross Yamhill/Druchamp//Daws/Maris Hobbit gave the lowest genetic variance for plant height (41.11) while the cross Yamhill/Daws//Maris Hobbit/Druchamp resulted in the highest genetic variability in subsequent progeny (144.07) for the same trait.

Three models were used for predicting double cross performance. Model I and Model III place primary emphasis on additive gene action and assume that order of paring is of little or no importance. Model II permits the recognition of nonadditive effects arising from dominance or epitasis. As for three-way crosses, by knowing the nature of gene action controlling the trait a more reliable choice of a predicting model can be made.

Similar results observed with single and three-way crosses were also found for double crosses. The combinations with high total GCA gave higher progeny population means than the low total GCA combinations. Therefore the best parental combination for grain yield in double crosses would be the combination of those parents with the highest total GCA for grain yield. This result again confirms that total GCA can be a new tool to predict performance of wheat crosses.

Genotype x Environment Interaction

Genotype x environment interactions are very important especially to the plant breeder who aims to have a cultivar with wide adaptability. To insure wide adaptation, the plant breeder tests selected lines for several years in several locations. The magnitude of the genotype x environment interaction can be revealed through the use of the analysis of variance. In this study, there was a significant interaction between genotypes and environments for plant height. This interaction was found to be important statistically only within parents. The cultivar Yamhill responded differently in relation to other cultivars when grown at the two different locations. It was relatively tall at the Hyslop location but was one of the shortest cultivars at the Pendleton location. No significant genotype x environment interaction was found for tiller number, harvest index, or grain yield; therefore the prediction and the conclusions drawn based on the data obtained at one location might be applied to another location as well for these traits. However, for stability in plant height Yamhill is not recommended as a parent especially when the Pendleton location is the target area for commercial production.

The results of this investigation indicated that "Total GCA" can be used in identifying the appropriate cross combinations. When simply inherited traits are involved, mid-parent values are very useful in predicting the performmace of the resulting single cross progeny. In predicting the performance of three-way crosses, the two predicting models (Model I: A/B//C = 1/4(A + B) + 1/2 C and Model II: A/B//C = 1/2(A x C) + 1/2(B x C)) both gave high correlation coefficients between actual and predicted performance for all traits measured. The order in which parents were combined in a three-way cross was important with the top cross parent having more influence upon progeny than either parent in the original single cross. Total GCA of the individual parent was important and would be a useful guide for the choice of the top cross parent.

In predicting the performance of resulting progeny in subsequent generations for double crosses, all three models analogous to those used in the production of hybrid corn could be used for plant height and harvest index. Model III which is similar to "Total GCA" however, showed some value in predicting tiller number and grain yield in the F_1 generation. The order in which parents were combined in a double cross was not important for grain yield, however it was important in the other three traits measured. Total GCA of the individual parents could serve again as an indication as to the development of the most promising cross combination for all the traits studied.

SUMMARY AND CONCLUSIONS

The objective of this study was to provide the wheat breeder with information concerning the identification of the most promising cross combination for either conventional or hybrid breeding programs.

To obtain such information, five winter wheat cultivars currently used in breeding programs (Yamhill, Stephens, Daws, Maris Hobbit, and Druchamp) were crossed in all possible combinations of single, three-way, and double crosses. F_1s, F_2s and parents were planted in randomized complete blocks with two replications at the Hyslop Agronomy Farm and at a site near Pendleton. Plant height, tiller number, harvest index, and grain yield were recorded from individual plants.

Analyses of variance were performed to determine if there were significant differences among parents, crosses, and generations. Combining ability analysis was conducted to evaluate the type of gene action involved. General and specific combining ability were computed for each parent and each single cross.

Two models were introduced to predict the performance of three-way crosses. The correlation coefficients between actual and predicted performance were calculated.

Three models were applied in predicting the performance of double crosses. The correlation coefficients between actual and predicted performance given by each model were obtained.

Genotype x environment interactions were examined. Yield responses and the ability of creating genetic variability in single, three-way, and double crosses were compared. Based on the experimental materials in this study the following conclusions were drawn:

1. General as well as specific combining ability (GCA and SCA respectively) were important for plant height and harvest index, while GCA was predominant for tiller number.
2. GCA was very useful in the choice of parents and the choice of cross combinations in single, three-way, and double crosses. The combination with the highest total GCA (sum of GCA of all parents involved) for a given trait gave the highest population mean values in the resulting progeny for that trait.
3. Grain yield produced by single and double crosses in the first generation was not significantly different but did differ significantly from the grain yield of three-way crosses at Hyslop.
4. Single crosses produced significantly higher grain yield than three-way crosses but they were not significantly different from that of double crosses in the first generation when averaged across the two locations.

5. Grain yield produced by single, three-way, and double crosses was not significantly different in the F_2 generation.
6. Double crosses created the most genetic variability in the F_1 generation for plant height and grain yield.
7. Three-way crosses generated more genetic variability in the F_2 generation for grain yield than single crosses but the opposite was true for plant height.
8. The top cross parent in a three-way cross had more influence upon the progeny than the original single cross parents, especially the low GCA top cross parent.
9. The mid-parent value was useful in predicting plant height, tiller number, and harvest index, but it could not accurately predict yield of the progeny resulting from single crosses.
10. F_1 as well as heterosis estimates were useful in predicting plant height, tiller number, and harvest index of single crosses.
11. Both models [Model I: (A x B) x C = 1/4(A x B) + 1/2 C and Model II: (A x B) x C = 1/2(A x C) + 1/2(B x C)] gave satisfactory predicting results in all traits under this study for the F_1s and F_2s of three-way crosses.
12. All three models (Model I: the mean performance of six possible single crosses among a set of four parents, Model II: the average performance of four

nonparental single crosses, and Model III: the average performance of four parents involved) were useful in predicting plant height and harvest index, while only Model III was appropriate in predicting tiller number and grain yield for double crosses.

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