AN ABSTRACT OF THE THESIS OF

OSCAR CACERES for the M.S. in Farm Crops
(Name) (Degree) (Major)

Date thesis is presented April 29, 1963

Title SINGLE CROSS PROGENY EVALUATION IN TALL FESCUE, FESTUCA ARUNDINACEA, SCHREB.

Abstract approved [redacted]
(Major Professor)

All possible single crosses from three different maturity groups of 27 selected parental genotypes of tall fescue were established in a randomized block experiment to be evaluated in 1962 for five agronomic characters: height, width and maturity per plant; self-seed yield per plant; and forage yield per plant. For each character, general and specific combining ability effects, relationship among these characters and heritability estimates based on mean square expectations were obtained.

Results of this study indicate that genetic diversity present in the original parental population resulted in significant differences among maturity groups for the characters measured, with the exception of self-seed yield. The variability within each group was small and significant only for maturity and self-seed yield in the

intermediate group and for height and maturity in the late group, indicating that the progenies were quite uniform for the other characters. Significant correlation coefficients were noted between forage yield with height and width of the plant. This significant association was observed in all three maturity groups.

Estimates of heritability in narrow sense for maturity and self-seed yield in the intermediate maturity group were 0.19 and 0.46, respectively. With the preponderance of additive gene effects for self-seed yield, the value of breeding material for this character may be indicated early in a breeding program.

SINGLE CROSS PROGENY EVALUATION IN TALL FESCUE, *FESTUCA ARUNDINACEA*, SCHREB.

by

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A THESIS

submitted to

OREGON STATE UNIVERSITY

in partial fulfillment of
the requirements for the
degree of

MASTER OF SCIENCE

June 1963

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Date thesis is presented April 29, 1963

Typed by Nancy Kerley

ACKNOWLEDGMENTS

The author wishes to extend his sincere thanks to Dr. R. V. Frakes for his encouragement and guidance during the progress of this study and for the helpful criticisms and suggestions in the preparation of this manuscript.

Appreciation is also extended to Drs. J. R. Cowan and W. H. Foote for the careful reading of the manuscript, and Mr. Lewis Johnson for his help and valuable suggestions in laboratory and field work.

The writer is also grateful to the Farm Crops Department for making land and facilities available for this study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES (continued)

LIST OF APPENDIX TABLES

SINGLE CROSS PROGENY EVALUATION IN TALL FESCUE, *FESTUCA ARUNDINACEA*, SCHREB.

INTRODUCTION

Tall fescue (*Festuca arundinacea*, Schreb.), is one of the most important forage crops in the United States because of its remarkable adaptation to different environments.

The breeder strives for the improvement of characters in the plant species, and these characters may or may not respond to the manipulation of the gene system. There is a definite necessity for information on heritability and combining ability of progenies and that of their selected parents, and this information is an indispensable prerequisite in determining the eventual breeding program and the development of improved varieties.

The recognition of gene action involved in the expression of a particular character is an important factor in selecting parental plants in the cross-pollinated crops. Selection in some perennial forage legumes and grasses based on combining ability is being practiced, but as yet there is no publication of similar studies conducted with tall fescue.

The present investigation represents a phase of a long-time program to gain more information on the relative merits of several types of progeny for evaluation of selected tall fescue parental genotypes, and its objectives were:

1. To investigate the relative importance of general and specific combining effects for characters measured in tall fescue.
2. Obtain a knowledge of the type of gene action involved in the quantitatively inherited characters measured for three different maturity groups of tall fescue.
3. Determine the relationship among these characters based on simple correlation coefficients.
4. Obtain heritability estimates based on mean squares expectations.

REVIEW OF LITERATURE

Breeding methods in forage crops are based on gene action, and estimates of the gene action conditioning quantitative characters are obtained through progeny tests or tests for combining ability. Allard (1, p. 470) defines progeny test as a test of the value of the genotype based on the performance of its offspring produced in some definite system of mating. Studies of combining ability were conducted extensively with corn at the same time that hybrid varieties were developed, and later, this concept was applied to the breeding of other crops, including forage species.

According to Sprague and Tatum (21, p. 923-932), variance of general combining ability is largely additive genetic variance, while specific combining ability variance is largely dominance variance. It was found with untested corn lines that variance of general combining ability was larger than variance of specific combining ability, indicating that the additive effects were much greater than the epistatic and dominance effects. In previously tested lines, variance of specific combining ability was greater because of selection and elimination of variation with respect to average performance in hybrids. A method is presented for evaluating the relative importance of genes contributing to general combining ability and specific combining ability in the yield of single crosses in corn.

Rojas and Sprague (19, p. 462-466), utilizing a number of highly selected inbred lines of corn in two tests over a period of four years, found that variance of specific combining ability was consistently larger than variance of general combining ability in the individual experiments.

Sentz et al. (20, p. 53) evaluated diallel crosses among eight lines constituting a synthetic corn variety. These were evaluated in the F_1 and S_1 (F_1 selfed) generations at two locations. These lines were selected as parents for their agronomic characteristics and specific combining ability. Data were recorded for grain yield, maturity and stalk lodging.

Mean square expectations for the analysis of a diallel experiment have been derived for an arbitrary number of generations of selfing. General combining ability variance for yield was several times greater than that for specific combining ability in both generations. General combining ability x year x location variance was the only important interaction. Comparison of genetic variances in both generations demonstrates the possibility of using S_1 generations for diallel experiments.

Rinke et al. (18, p. 74) intercrossed 15 unrelated inbred lines of corn in all possible single-cross combinations and tested as single crosses and inbreds. Data were recorded on plant height, ear length, good ears per plant, moisture content at harvest, and grain yield. For all characteristics, the mean values of the single-cross arrays were in positive relation to the classification of their parental inbreds. None of the single crosses from inferior x inferior parents were equal to the best single cross from superior x superior. For the characters, plant height, good ears per plant, yield of grain and performance index, superior and inferior crosses gave some single-crosses equal to the best of the superior x superior crosses, although the frequency of the occurrence of these was not as great.

Kehr (12, p. 53-55) studied the relative magnitude of general versus specific combining ability effects and heritabilities for four agronomic characters in a diallel series of six alfalfa clones. The clones were selected on the basis of their high general combining ability for forage yield but were unselected for growth habit and rate of recovery.

The estimated variance component for general combining ability was slightly larger than that for specific combining ability for fall growth habit and rate of recovery. The estimated variance component for specific was much larger than that for general combining ability for forage yield and spring growth habit. Thus, additive appeared more important than non-additive gene action in determining differences in fall growth habit and rate of recovery, but forage yield and spring growth habit differences were determined more by non-additive than additive gene action.

Carnahan et al. (6, p. 511-516) studying the diallel crosses among 14 alfalfa clones indicated that seedling vigor and fall growth habit were highly correlated and that each trait was highly heritable. Furthermore, general combining ability variance was much higher than specific combining ability variance for both characters investigated. Additive gene effects appeared relatively more important than epistatic and other non-additive gene effects in conditioning seedling vigor and fall growth habit.

Frakes et al. (7, p. 210-212) has reported that natural height and longest stem measurement of F_1 and F_2 progeny from diallel crosses of alfalfa responded to the effects of general combining ability, whereas natural width and number of stems per plant were low in their response to the effects of general combining ability. Dry matter yield was intermediate among the four measurable components in respect to general combining ability response. This study showed that of four measurable yield components, two lend themselves to the synthetic breeding approach; while the other two would be better suited to the breeding program designed to take advantage of gene interaction.

Binham and Pedersen (2, p. 47) used diallel crosses to determine the general and specific combining ability of five selected alfalfa clones for seedling vigor and seed yield in the year of establishment.

General combining ability effects were significant at the P = 0.01 level for both characters. Specific combining ability effects for seed yield were significant at the P = 0.05 level. A significant correlation between seedling vigor and seed yield was obtained.

Buker and Davis (5, p. 48), working with alfalfa, used an eight-clone diallel to estimate the variances contributed by general and specific combining ability. The parental clones had previously been polycross progeny tested. In this earlier test, four clones had high yielding progeny and four clones had low yielding progeny. The eight clones were crossed by hand in all combination without emasculation. Reciprocals were kept separate. The seed was planted in single-row plots, ten feet long, spaced one foot apart, and replicated four times. Three yield harvests were taken in 1960. Leaf-stem separations were made on samples from the second and third cuttings, and the leaf-stem ratio determined. Other measurements were natural height, natural width and crown width. Visual estimates of vigor and diseases were assigned each row. Analysis of the data by the methods described by Griffing indicated that both general combining ability and specific combining ability were present for most of the characters evaluated. Reciprocal differences were not present. The results would indicate that alfalfa improvement programs should be oriented to utilize variation due to specific combining ability.

Riedl and Liang (17, p. 55) compared the performance of single-cross progenies of alfalfa with multi-clone progenies developed from the same clones. Most of the single-cross progenies excelled the multi-clone progenies. Plantheight and number of tillers were the most important components of forage yield. Positive correlation of +0.8 and +0.67 were found between forage yield and plant height, and between forage yield and number of tillers, respectively. Plant height and number of tillers were also positively correlated, r = 0.38. In the study of combining ability for three agronomic traits in a diallel series of crosses between five alfalfa clones, the variance component for specific combining ability was larger than for general combining ability for forage yield and slightly larger for number of tillers. The variance component for general combining ability was larger than for specific combining ability for plant height.

Theurer and Elling (22, p. 56) made by hand pollination in the greenhouse diallel crosses among five clones of alfalfa, the five S_1 progenies and the 26 possible second generation synthetic combinations of the same clone. Seedlings were inoculated and transplanted to the field. Diallel analysis of the single-cross data indicated that the general combining ability variance was 7-1/2 times greater than that for specific combining ability. However, both variances were significant at the fiver percent level. In general, synthetic varieties derived from clones having high combining ability were high and those from low combining clones were low. However, the exact performance of a given synthetic could not be accurately determined from single crosses or S_1 progenies of the related clones.

Wilcox and Wilsie (25, p. 57), working with alfalfa, conducted field tests of F_1 progenies of 12 elite regional clones crossed with two Iowa clones, with reciprocal crosses planted in adjacent plots. Observations made during three years indicated that in some crosses the reciprocals differed in growth habit, flower color and yield. Reciprocal differences were not always found to be consistent with these obtained in the original field. Analysis of several characters indicated that reciprocal differences may be only of minor importance as far as specific combining ability and general combining ability are concerned.

Bolton (3, p. 97-126) crossed in all possible combination a group of alfalfa plants open-pollinated in origin and a group of inbred plants. Yields of seed and forage were obtained from the crossed progenies and very great differences in the combining ability of parent plants were found. Results were not conclusive, but there were indications that tester plants may be useful in determining combining ability where large numbers of plants are to be tested. For primary test of combining ability of selected parent plants, the use of progenies grown from polycross seed and for the final selection seed from all possible single crosses is suggested.

Morley et al. (15, p. 635-651) studied general and specific combining ability for summer and winter production in hybrids between ten alfalfa varieties that differed widely as spaced plants in winter and summer production. It was found that variance for general combining ability was approximately equal to that for specific combining ability for summer production, but the variance for general was greater than that for specific for winter production.

Tysdal and Crandall (24, p. 293-306) demonstrated the value of the polycross progeny test as a method of testing general combining ability of seven selected clones of alfalfa. The combining ability rating as shown by polycross yields were compared with the rating as indicated by the average yields of three to five single crosses. The results indicated that marked breeding progress could be achieved by the selection of alfalfa plants with high combining ability.

Timothy et al. (23, p. 252-255) measured general and specific combining ability of bromegrass and compared average single crosses performance with clonal and polycross progeny performance. General combining ability was more important than specific combining ability for forage yield, seed yield, leaf spot, bacterial blight and scald. Specific combining ability was predominant for plant height, noted to a minor extent for seed yield and leaf spot, and appeared to be absent for forage yield, bacterial blight and scald. There was reasonably close agreement in performance of clones, average single cross performance and polycross progeny performance for most of the characters studied.

Hanson et al. (9, p. 84-87) compared the combining ability of 18 parental clones of orchardgrass and 52 of their I_4 lines. The general combining ability of the majority of the I_4 lines investigated was not materially different from that of their parental clones. The results indicate, however, that some lines which are better or poorer combiners than the original selection might be isolated in an inbreeding program.

Knowles (13, p. 275-302) conducted studies of combining ability with single open-pollination plants of commercial strains of bromegrass and crested wheatgrass. Combined ability of plants was measured by the forage production of progenies of various types, including controlled single crosses, open-pollination progenies and, in certain cases, polycross and top-cross progenies.

Significant differences in combining ability were noted among plants in both groups. Open-pollination progenies of selected plants gave indices of combining ability in agreement with those of controlled crosses in crested wheatgrass, but not in bromegrass. In both, bromegrass and crested wheatgrass, little relationship was found between the yields of parent clones and their progeny classes. This fact emphasizes the importance of using progeny rather than clonal lines in the evaluation of plants of these grasses for yielding potential.

Buckner (4, p. 177-180) suggested that a tall fescue variety of improved palatability could be developed by selection and that grazing animals might be used to screen spaced plants for this quality. Those lines of improved palatability were secured by a program of inbreeding continued for four successive generations. The inbred lines became less vigorous with each generation of inbreeding but little relation existed between vigor and palatability. It is suggested that the selected lines should be used effectively in the formation of a synthetic variety but further screening for general combining ability for palatability is required.

Kalton and Leffel (10, p. 370-373) evaluated all possible single crosses among 11 non-inbred clones of orchardgrass for early spring vigor, leaf disease reaction, bloom date, panicle production and forage yield. Variances attributable to general combining ability were greater than for specific combining ability in all comparisons. Disease score was the only character exhibiting significant specific combining ability.

Kalton _et al_. (11, p. 481-486) studied parent-inbred progeny relationships in orchardgrass. Desirable clones were selfed and vegetatively propagated the following year for direct comparison with their inbred progenies in the same plot. Differences among self progenies were apparent in inbreeding depression and segregation for various characters. Heritabilities for panicle number and forage yield were negative or low, signifying environment was the major influence in plant to plant differences for these characters. Differences in height, leafiness, and spring vigor among plants appeared to be conditioned by genetic causes and the heritability percentages ranged from 35 to 56 percent.

McDonald *et al*. (14, p. 20-25) evaluated self and open-pollination progenies of 40 selected bromegrass clones for yield and other characters. All characters including vigor, spread, panicle score, and height were significantly associated with yield. Heritabilities calculated from regression of open-pollination progeny means and S_o clonal means were similar for all characters and ranged from 26.3 to 44.1 percent.

Oldemeyer and Hanson (16, p. 158-162) compared three different means of evaluating combining ability in orchardgrass, wide polycross, restricted polycrosses and single crosses. Considering yield, significant correlations were obtained in relating polycross and single cross progenies to the parents; and wide polycross to restricted polycross progenies. Considerable variation among the single-crosses should indicate the expression of specific combining ability.

MATERIAL AND METHODS

The seed of 109 single crosses of tall fescue from three diallel crosses of 27 selected parental genotypes were planted into vitabands and established in a field nursery at Hyslop Farm on October 18, 1961.

The 27 parents were selected out of 9,000 plants that constituted the original source nursery. Selection was based on self-sterility, seed and forage potential, and nutritive value on the basis of crude protein and chromogen content (Table 1). The selected parents were grouped into early, intermediate and late maturity, according to the mean flowering date, and each group included eight, nine and ten parents, respectively, which give a total of 109 possible single crosses: 28 in the early maturity group, 36 in the intermediate and 45 in the late maturity (Table 2). The seed of each single cross used in the present experiment was obtained from single cross blocks in which each parent included in the cross was increased vegetatively and planted in paired rows of eight propagules to facilitate the controlled natural cross-pollination after enclosing unemasculated inflorescences in the same parchment bag. Each single cross was represented by five-plant rows in each of the two replications of a randomized block with rows and plants three feet apart.

Table 1. Identification of selected parental clones used to make the single crosses in each maturity group.

Culture	Flowering Date-May[1]	Chromogen[2]	% Crude Protein[2]	Grams Seed Yield[3]	% Self Fertility[4]	Origin
			Early Maturity (5-14 to 5-20)			
304	20	140	9.89	2.57	9.7	Goar
314	14	121	8.65	1.76	7.0	Goar
315	19	130	10.34	2.62	6.4	Goar
339	18	115	8.42	3.40	12.0	S-170
340	16	123	9.43	2.96	2.9	S-170
342	16	140	8.55	3.49	5.2	S-170
351	20	125	8.15	3.83	8.3	S-170
352	20	138	8.73	3.93	7.4	S-170
			Intermediate Maturity (5-21 to 5-25)			
296	24	132	10.52	3.53	15.5	Alta
298	22	132	10.05	3.44	2.1	Alta
299	22	162	9.98	4.42	9.5	Alta
311	23	151	8.70	3.35	5.5	K-31
329	23	135	9.05	3.00	4.6	K-31
359	24	127	10.30	3.04	7.6	Mo. #1
366	25	147	11.49	2.60	5.6	Mo. #2
368	22	125	8.99	4.04	7.4	Mo. #3
374	23	138	8.76	2.18	7.5	Mo. #4
			Late Maturity (5-26 to 5-29)			
309	26	139	12.06	3.53	7.8	K-31
310	28	137	9.50	2.97	8.3	K-31
326	28	145	10.16	3.11	7.7	K-31
327	27	123	10.28	2.41	4.8	K-31
331	29	144	9.58	2.66	3.0	K-31
364	28	155	11.29	1.78	3.5	Mo. #2
370	26	136	9.98	3.33	1.7	Mo. #3
372	26	125	9.59	2.56	7.6	Mo. #3
379	27	133	9.72	1.43	19.5	Mo. #4
380	29	142	9.51	1.43	1.4	Mo. #4

1. 1957-58 average. 2. Clippings made 7-10 through 7-24-57 at similar maturity stages. 3. Five panicle samples, 1955.
4. Comparison of open vs. self-pollinated seed set.

Table 2. Identification numbers used for the 109 single crosses in the three different maturity groups of 27 selected parental clones of tall fescue.

Parent	Intermediate Maturity Group, Entry 1 to 36								
	296	298	299	311	329	359	366	368	374
296	---	36	35	34	21	20	19	31	32
298		---	25	26	28	27	29	30	33
299			---	9	8	7	13	14	15
311				---	4	5	6	16	17
329					---	18	24	23	22
359						---	12	11	10
366							---	1	2
368								---	3
374									---

Parent	Early Maturity Group, Entry 37 to 64							
	304	314	315	339	340	342	351	352
304	---	39	40	45	46	51	52	57
314		---	58	63	64	62	59	56
315			---	53	50	47	44	41
339				---	38	37	42	43
340					---	48	49	54
342						---	55	60*
351							---	61*
352								---

Parent	Late Maturity Group, Entry 65 to 109									
	309	310	326	327	331	364	370	372	379	380
309	---	95	96	97	98	99	100	101	102	103
310		---	104	105	106	107	108	109	94	93
326			---	92	91	90	89	88	87	86
327				---	85	84	83	82	81	80
331					---	65*	66	67	68	69
364						---	70	71	72	73
370							---	74	75*	76
372								---	77	78
379									---	79
380										---

* Missing Entry.

<u>Measurements</u>

All plants in the nursery were evaluated individually in 1962 for agronomic characters in the following manner:

Height - Measured in centimeters from the ground level to the highest part of the plant on (1) May 12, and (2) August 19.

Maturity - Each plant was scored on a scale of one to nine on May 12. These ratings were as follows: 1, no panicles; 2, 3, 4, one to several panicles formed but not visible; 5, few small panicles; 6, 7, 8 few to several panicles completely developed; 9, some panicles at the stage of anthesis.

Width - Measured in centimeters across the widest diameter of the plant; August 19.

Forage Yield - Plants in each row were cut on September 23, with a sickle at a height of approximately three inches above the soil surface. The forage from each row was bagged and air-dried at 50^{o}-60^{o}C oven for 8 to 12 hours. Row yields were recorded in grams.

Selfed Seed Yield - The inflorescences were enclosed in a parchment bag applied prior to anthesis. Each bag was harvested and threshed separately in a small friction-type thresher and cleaned by means of a hand screen and a South Dakota Blower. The clean seed was weighed on an electric scale and the data recorded in milligrams.

All the measurements with the exception of forage yield were recorded on mark-sensed IBM cards.

Statistical Analysis

Data for each agronomic character were analyzed statistically. The F-values were computed under the assumption that the variables were fixed, and the analysis of variance proposed by Griffing (8) was used for the diallel analysis.

A combined analysis of variance was calculated for each character measured in each of the three maturity groups, and after testing the null hypothesis that there are no genotypic differences among the single crosses, a combining ability analysis was continued (Table 3). This analysis was conducted for each group separately and corresponded to Griffing's (8) Experimental Method 4 which includes one set of F_1's but neither parents nor reciprocals.

In the model for the combining ability analysis, the restrictions

$$\sum g_i = 0 \text{ and } \sum_{i \neq j} s_{ij} = 0 \text{ (for each j)}$$

are imposed in the combining ability effects. With this restriction, only the intermediate maturity group was suitable for the diallel analysis.

Table 3. Expected mean squares in the analysis of variance for combining ability, Model I.

Source of Var.	D. F.	S.S.	M.S.	Expect. M.S.
G. C. A.	p-1	S_g	M_g	$\sigma^2 + (p-2)(\frac{1}{p-1}) \sum_i g_i^2$
S. C. A.	p(p-3)/2	S_s	M_s	$\sigma^2 + \frac{2}{p(p-3)} \sum\sum_{i<j} s_{ij}^2$
Error	m x 2	S_e	M_e'	σ^2

Where p = No. of parents.

$$S_g = \frac{1}{p-2} \sum X_{i.}^2 - \frac{4}{p(p-2)} X_{..}^2$$

$$S_s = \sum_{i<j} \sum x_{ij}^2 - \frac{1}{p-2} \sum X_{i.}^2 + \frac{2}{(p-1)(p-2)} X_{..}^2$$

S_e = Error S.S. from the combined analysis.

M_e' = Error M.S. divided by the number of replications.

m = Degrees of freedom of experimental error x number of reps.

The differences within classes of effects were tested by F ratios. To test general combining ability effects $F = M_g/M_e'$, and to test specific combining ability effects $F = M_s/M_e'$.

The effects were estimated as follows:

$$g_i = \frac{1}{p(p-2)} (pX_{i.} - 2X..)$$

and $$s_{ij} = x_{ij} - \frac{1}{p-2} (X_{i.} + X_{j.}) + \frac{2}{(p-1)(p-2)} X..$$

The variances of effects were estimated as follows:

$$Var(g_i) = (g_i)^2 - \frac{p-1}{p(p-2)} \sigma^2$$

$$Var(s_i) = \frac{1}{p-1} \sum_{j \neq i} s_{ij}^2 - \frac{p-3}{p-2} \sigma^2$$

A detailed example for the statistical analysis of self seed yield is given in Appendix Table 10.

Simple correlation coefficients were calculated in each group of maturity among the six characters measured to estimate the intensity of association of these characters. The following correlations were studied: Height one with height two; height one with maturity; height one with width; height one with self-seed yield; height one with forage yield; height two with maturity; height two with width; height two with self seed yield; height two with forage yield; maturity with width; maturity with self-seed yield; maturity with forage yield; and self-seed yield with forage yield. For each test the correlation coefficient between the mean of the respective variables was determined; subsequently 15 linear correlation coefficients were obtained.

Estimates of heritability in the narrow sense were obtained from the combining ability components for maturity and self-seed yield (Table 4).

According to Griffing (8, p. 489), the additive genetic variance is equal to double the variance for general combining ability and the non-additive genetic variance is equal to the specific combining ability variance

$$\sigma_a^2 = 2\,\sigma_g^2$$
$$\sigma_{na}^2 = \sigma_s^2$$

The genetic variance σ_G^2 is equal to $2\,\sigma_g^2 + \sigma_s^2$, and the phenotypic variance σ_p^2 is equal to the genetic variance plus the error variance

$$\sigma_p^2 = \underbrace{2\,\sigma_g^2 + \sigma_s^2}_{\sigma_G^2} + \sigma_e^2$$

Heritability is narrow sense was estimated by the ratio of the additive genetic variance over the phenotypic variance.

$$H_{ns} = \frac{2\,\sigma_g^2}{2\,\sigma_g^2 + \sigma_s^2 + \sigma_e^2}$$

Table 4. Expected mean squares in the analysis of variance for combining ability, Model II.

Source of Var.	D. F.	S. S.	M. S.	Expect. M. S.
G. C. A.	p-1	S_g	M_g	$\sigma^2 + \sigma_s^2 + (p-2)\,\sigma_g^2$
S. C. A.	p(p-3)/2	S_s	M_g	$\sigma^2 + \sigma_s^2$
Error	m x 2	S_e	M_e	σ^2

EXPERIMENTAL RESULTS

Agronomic Performance

A measure of general agronomic performance of the single crosses within each maturity group was obtained by computing means per row. These means are given in Appendix Tables 1 to 10.

Data for each agronomic character were analyzed statistically in accordance with standard procedures, and the analysis of variance for the three different groups of single crosses were calculated as a randomized block using row means as the basic unit. In the combined analysis of variance for the three maturity groups, the treatment sum of squares was partitioned into among groups and within groups. To test the hypothesis that the means of the crosses in each maturity group are equal, the within sum of squares was divided into the three groups and the experimental error mean square used for denominator in the F-test of significance. This breakdown is shown in Table 5 to 10.

The single crosses in each maturity group exhibited considerable variation in the different characters measured; however, only in four cases were these differences significant (Table 11).

In the early maturity group, cross differences were not found in the six characters measured. In the intermediate maturity group,

Table 5. Combined analysis of variance for average height per plant in cms. as recorded on May 12, 1962, for the three different maturity groups.

Source of Variation	D. F.	S. S.	M. S.	F
Replication	1	534.85	534.85	
Treatment	93	75,594.02	814.99	
Among groups	2	65,868.00	32,934.00	301.92**
Within groups	91	9,926.02	109.08	1.66*
Early groups	21	1,917.66	91.32	1.39
Intermediate groups	35	2,161.06	61.74	0.94
Late group	35	5,847.30	167.06	2.55**
Error	93	6,095.54	65.54	
Total	187	82,424.41		

** F value exceeds the one percent level of significance.

* F value exceeds the five percent level of significance.

Table 6. Combined analysis of variance for maturity scored on a scale from 1 (early) to 9 (late) as recorded on May 12, 1962, for the three different maturity groups.

Source of Variation	D. F.			S. S.	M. S.	F	F-Table 5%
Replication	1			2.98	2.98	12.95**	3.96
Treatment	93			317.17	3.41	14.82**	1.44
Among groups		2		265.92	132.96	237.42**	3.11
Within groups		91		51.25	0.56	2.43**	1.44
Early group			21	3.17	0.15	0.652	1.69
Intermediate group			35	13.88	0.40	1.739*	1.57
Late group			35	34.20	0.98	4.261**	1.57
Error	93			21.33	0.23		
Total	187			341.48	1.83		

** F value exceeds the one percent level of significance.

* F value exceeds the five percent level of significance.

Table 7. Combined analysis of variance for average height per plant in cms. as recorded on August 19, 1962, for the three different maturity groups.

Source of Variation	D. F.			S. S.	M. S.	F
Replication	1			253.95	253.95	
Treatment	93			9,687.59	104.17	
Among groups		2		3,491.52	1,745.76	25.64**
Within groups		91		6,196.07	68.09	1.14
Early group			21	1,289.27	61.39	
Intermediate group			35	2,969.33	84.84	
Late group			35	1,937.46	55.36	
Error	93			5,545.53	59.63	
Total	187			15,487.07		

** F value exceeds the one percent level of significance.

Table 8. Combined analysis of variance for average width per plant in cms. as recorded on August 19, 1962, for the three maturity groups.

Source of Variation	D. F.	S. S.	M. S.	F
Replication	1	5,502.62	5,502.62	
Treatment	93	22,930.45	246.56	
Among groups	2	5,082.19	2,541.09	12.96**
Within groups	91	17,848.26	196.13	0.99
Early group	21	1,868.38	88.97	
Intermediate group	35	10,762.37	307.50	
Late group	35	5,217.51	149.07	
Error	93	18,321.65	197.01	
Total	187	46,754.72		

** F value exceeds the one percent level of significance.

Table 9. Combined analysis of variance for selfed-seed yield per panicle per plant in mgrs. as recorded on July, 1962, for the three different maturity groups.

Source of Variation	D.F.	S.S.	M.S.	F	F-Table 5%
Replication	1	24,642.69	24.642.69	8.820**	3.96
Treatment	93	470,470.39	5,058.82	1.809*	1.44
Among groups	2	18,238.60	9,119.30	1.835	3.11
Within groups	91	452,231.79	4,969.58	1.778**	1.44
Early group	21	83,077.94	3,956.10	1.415	1.69
Intermediate group	35	259,193.30	7,405.52	2.649**	1.57
Late group	35	109,960.54	3,141.75	1.124	1.57
Error	93	259,942.22	2,795.08		
Total	187	755,055.30			

** F value exceeds the one percent level of significance.

* F value exceeds the five percent level of significance.

Table 10. Combined analysis of variance for forage yield per plant in grams (dry weight) as recorded on September 23, 1962, for the three maturity groups.

Source of Variation	F	S.S.	M.S.	F
Replication	1	249.02	249.02	
Treatment	93	49,491.49	532.17	
Among groups	2	19,039.67	9,519.83	2.84**
Within groups	91	30,451.82	334.63	0.85
Early group	21	8.446.30	402.20	
Intermediate group	35	12,292.79	351.22	
Late group	35	9,712.72	277.51	
Error	93	36,563.03	393.15	
Total	187	86,303.54		

** F value exceeds the one percent level of significance.

Table 11. Summary of mean squares from the combined analysis of variance for three different groups of maturity of tall fescue.

	Early Maturity	Intermediate Maturity	Late Maturity
Height-1	91.32	61.74	167.06**
Maturity	0.15	0.40*	0.98**
Height-2	61.39	84.84	55.36
Width	88.97	307.50	149.07
Forage yield	402.20	351.22	277.51
Selfed seed yield	3,956.10	7,405.52**	3,141.73

** F value exceeds the one percent level of significance.

* F value exceeds the five percent level of significance.

the only group which had no missing entries, differences between genotypes were found to exist for maturity and selfed-seed yield. In the late maturity group, as shown in Table 11, highly significant differences between crosses for height one and maturity were found.

Combining Ability Analysis

The combining ability analyses are given in Tables 12 to 16. Considering that in only the intermediate maturity group all the possible single crosses $\frac{p(p-1)}{2}$ were represented, a combining ability analysis was performed for those two characters in which the genotypes were significantly different. Two-way tables, such as Tables 12 and 14, were prepared and the total and mean values for the single crosses were recorded.

The analysis of variance for maturity and seed yield is given in Tables 13 and 15, respectively. For both characters, the mean square for general combining ability was greater than that for specific combining ability, and general combining ability was significant in each case. Estimates for general combining ability effects were obtained to determine the respective variances associated with each parent (Tables 16 and 17) for maturity and self-seed yield in the intermediate maturity group and were not presented for specific combining ability because in the analysis of variance the effects for specific combining ability were not significant. In this part of the analysis, it

Table 12. Intermediate maturity group. Diallel Table. Maturity scored from 1 to 9. F_1 mean values.

	296	298	299	311	329	359	366	368	374	TOTAL
296	---	5.9	6.9	5.7	5.7	6.8	5.8	5.4	5.9	48.10
298	5.9	---	6.4	5.0	5.6	5.8	6.2	5.85	6.0	46.75
299	6.9	6.4	---	6.2	6.8	6.05	5.85	7.0	5.9	51.10
311	5.7	5.0	6.2	---	5.9	5.9	5.8	5.3	6.4	46.20
329	5.7	5.6	6.8	5.9	---	6.7	5.8	5.8	5.55	47.85
359	6.8	5.8	6.05	5.9	6.7	---	6.2	5.8	5.8	49.05
366	5.8	6.2	5.85	5.8	5.8	6.2	---	6.15	5.7	47.50
368	5.4	5.85	7.0	5.3	5.8	5.8	6.15	---	6.2	47.50
374	5.9	6.0	5.9	6.4	5.55	5.8	5.7	6.2	---	47.45
										431.50
TOTAL										215.75

Table 13. Combining ability analysis for maturity scored from 1 to 9.

Source of Var.	D.F.	S.S.	M.S.	F
G.C.A.	8	2.33	0.29	2.41*
S.C.A.	27	4.61	0.17	1.42
Error	35x2	8.31	0.12	

Table 14. Intermediate maturity group. Diallel Table. Selfed seed yield per panicle in mgms. F_1 mean values.

	296	298	299	311	329	359	366	368	374	TOTAL
296	--	14.95	124.55	79.90	18.05	122.55	45.80	33.95	65.20	504.95
298	14.95	--	13.30	22.10	8.00	103.30	10.70	18.70	24.45	215.50
299	124.55	13.30	--	62.30	51.35	230.00	58.10	57.65	51.65	648.90
311	79.90	22.10	62.30	--	287.05	148.35	61.90	31.20	93.45	786.25
329	18.05	8.00	51.35	287.05	--	129.95	94.50	85.90	70.65	745.45
359	122.55	103.30	230.00	148.35	129.95	--	62.30	84.80	141.45	1022.70
366	45.80	10.70	58.10	61.90	94.50	62.30	--	15.25	17.05	365.60
368	33.95	18.70	57.65	31.20	85.90	84.80	15.25	--	66.90	394.35
374	65.20	24.45	51.65	93.45	70.65	141.45	17.05	66.90	--	530.80
										5214.50
TOTAL										2607.25

Table 15. Combining ability analysis for selfed seed yield per panicle in mgrs.

Source of Var.	D. F.	S. S.	M. S.	F
G. C. A.	8	70,283.79	8,785.45*	3.9539**
S. C. A.	27	59,312.86	2,196.77	0.9886
Error	35x2	155,539.09	2,221.99	

** F value exceeds the one percent level of significance.
* F value exceeds the five percent level of significance.

Table 16. Estimates of general combining ability effects and variances associated with each parent for selfed seed yield per panicle in mgrs.

Parent	g_i	$\sigma^2_{g_i}$
296	-10.63	- 169.2
298	-51.98	2419.7
299	9.93	- 183.6
311	29.55	591.0
329	23.72	280.4
359	63.33	3728.5
366	-30.54	650.5
368	-26.43	416.3
374	- 6.94	- 234.0

Table 17. Estimates of general combining ability effects and variance associated with each parent for maturity scored from 1 to 9.

Parent	g_i	$\sigma^2_{g_i}$
296	1.40	1.94
298	-10.75	115.54
299	28.40	806.54
311	-15.70	246.50
329	- 0.85	0.70
359	9.95	99.00
366	- 4.00	16.00
368	- 4.00	16.00
374	- 4.45	19.80

is possible to observe that the restriction $\sum g_i = 0$ is accomplished.

The last column in Tables 16 and 17 corresponds to the relative magnitude of the general variance contributed by each of the selected parents in the intermediate maturity group for the two characters studied.

Correlations of Characters

Important interrelationships to the plant breeder are those between yield and other agronomic characters, and a knowledge of any character highly associated with yield is of considerable value. Correlations among the characters measured in the three different groups of maturity appear in Table 18.

Heritability

The heritability estimates for maturity and self-seed yield in the intermediate group of maturity shown in Table 19 were calculated using the formulas previously mentioned. The estimates of additive genetic variance were used in the numerator and the total phenotypic variance was used as the denominator. The heritability estimates for maturity and self-seed yield were 19 percent and 46 percent, respectively.

Table 18. Inter-character correlations for the three different groups of maturity of tall fescue.

Characters		Early Maturity	Intermediate Maturity	Late Maturity
		n = 22	n = 36	n = 36
Height 1	- Height 2	0.379	0.472**	0.461**
Height 1	- Maturity	0.341	0.788**	0.921**
Height 1	- Width	0.251	0.420**	0.322
Height 1	- Self-Seed Yield	0.524*	0.186	0.363*
Height 1	- Forage Yield	0.179	0.424**	0.460**
Height 2	- Maturity	0.352	0.536**	0.405*
Height 2	- Width	0.959**	0.948**	0.932**
Height 2	- Self-Seed Yield	0.366	0.468**	0.002
Height 2	- Forage Yield	0.846**	0.852**	0.890**
Maturity	- Width	0.329	0.471**	0.276
Maturity	- Self-Seed Yield	0.366	0.209	0.385**
Maturity	- Forage Yield	0.279	0.446**	0.421**
Width	- Self-Seed Yield	0.245	0.407**	-0.008
Width	- Forage Yield	0.944**	0.903**	0.927**
Self-Seed Yield	- Forage Yield	0.286	0.375	0.071

** F value significant at one percent level.
* F value significant at five percent level.

Table 19. Genetic components of variance and heritability estimates for maturity and self-seed yield in the intermediate maturity group of tall fescue.

Component	Maturity		Self-Seed Yield	
σ_P^2	0.21		4,078.95	
σ_G^2	0.09		1,856.96	
$2\sigma_g^2$		0.04		1,882.48
σ_s^2		0.05		-25.52
σ_e^2	0.12		2,221.99	
$H_{ns} = \frac{2\sigma_g^2}{\sigma_P^2}$	0.19		0.46	

DISCUSSION

The objective of this experiment was the evaluation of selected parental genotypes of tall fescue by studying the single crosses obtained from the parental population.

A single cross progeny test which includes the complete series of single crosses between the selected parents is called a diallel cross. This type of progeny test considers the following assumptions: (1) The population is random mating and in equilibrium; (2) The parent clones are a random sample of the population with over-all gene frequencies equivalent to those of the larger population; (3) Reciprocal crosses give progenies with equivalent performance; (4) Percent cross fertilization to produce the single crosses is uniformly high, and the low amount of self-seed resulting in established seedlings does not bias the results; (5) Statistical techniques developed for diploid organisms may be used on this polyploid species. These assumptions are not always fulfilled without the investigators knowing the consequences of this situation. Other limitation of this progeny test is that not always sufficient seed is obtained from all the single crosses, and the diallel analysis can not be accomplished when most of the possible single crosses are not present in the experiment.

The agronomic performance of the three different maturity single-cross groups showed relatively little variability within each group for the characters measured. In the intermediate and late maturity groups, the single-cross families differed significantly in mean variance for two characters only, indicating that the single-crosses were quite uniform for these characters. The differences among groups were highly significant for all the characters with the exception of self-seed yield (Tables 5 to 10). These results are in agreement with the genetic diversity present in each of the maturity groups (see origin Table 1).

Due to the fact that only in the intermediate maturity group all the possible single crosses were represented, the combining ability analysis was conducted only for this group. This analysis for maturity shows a significant general combining ability effect, indicating that differences due to this effect does exist.

In the case of self-seed yield, general combining ability was of greater value than the effects of specific combining ability. The low specific combining ability variance associated with this group of parents would indicate that these selected genotypes may transmit uniformly this self-seed yield ability to the single crosses. These results show that additive gene effects are relatively more important than non-additive gene effects in conditioning maturity and self-seed yield.

In this study, correlations were used for expressing the interrelationships of the characters studied. Correlations between the second recorded height with width and forage yield, as well as width of the plants and forage yield were highly significant in the three groups of maturity. The first and second recorded heights were highly correlated only in the intermediate and late maturity groups; and also significant correlation is found in the last two groups for height one - maturity scores, height one - forage yield, and maturity scores - forage yield. In the early maturity group is also found significant correlations between height one and maturity scores. In the three maturity groups, a close association of forage yield with height and width was observed, while association of self-seed yield and other characters are irregular. Any interrelationship between yield and other character is important to the plant breeder and helpful in the initial phenotypic selection of the breeding material.

The values 0.46 and 0.19 obtained for heritability estimates in the narrow sense for the two characters analyzed in the intermediate maturity group indicate for self-seed yield an appreciable amount of additive genetic variance and for maturity that the non-additive genetic variance is as high relative to the additive genetic variance (Table 19). The fact that a large portion of the genetic variance is additive suggests that the breeder consider methods of breeding which permit capitalizing on this type of genetic variation.

SUMMARY AND CONCLUSIONS

All possible single crosses from three different groups of maturity of selected parental genotypes of tall fescue were established as individual spaced plants on October, 1961, in a randomized block nursery with two replications.

All plants in the nursery were evaluated individually for six agronomic characters and a diallel analysis was used to investigate the combining ability of these selected genotypes. The association between characters was measured by simple correlation coefficients and heritability estimates in narrow sense were obtained for maturity and self-seed yield in the intermediate maturity group.

The results and conclusions from this study were as follows:

1. The agronomic performance of the three different maturity single-cross groups showrelative small variability within each group in the characters measured. The single-cross families differed significantly in mean variance for two characters only in the intermediate and late maturity groups, indicating that the F_1's progenies were quite uniform for these characters. Highly significant differences among maturity groups were observed for all the characters measured except self-seed yield. These differences would be determined by the degree of genetic

diversity present in the original parental population.

2. Significant differences in general combining ability only were found among the single crosses for maturity and self-seed yield in the intermediate maturity group. These results show that additive gene effects appeared relatively more important than non-additive gene effects in conditioning these two characters.

   The low value of specific combining ability variances for self-seed yield would indicate that these selected genotypes transmit uniformly self-seed yield ability to the F_1's.

3. Highly significant correlation coefficients were noted between forage yield and height and forage and width of the plants for the three groups of maturity. Correlations between self-seed yield with height, width and maturity are observed, but are not consistent through the three different groups of maturity. These results indicate that the effect of height and width is constant in the production of forage in all the different genotypes.

4. The estimates of heritability in the narrow sense for two characters, maturity and self-seed yield, in the intermediate maturity group was made using expected mean squares from the diallel analysis. The estimate for

maturity was 0.19 and for self-seed yield 0.46. Additive gene effects appeared relatively more important than non-additive gene effects. With the preponderance of additive gene effects for self-seed yield, the value of breeding material may be indicated early in a breeding program.

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APPENDIX

Appendix Table 1. Early maturity single cross[1] means for plant height (cm.) and maturity (rating)[2], 1962.

Single Cross	May 12 Height	August 19 Height	Maturity
37	64.5	49.1	9.0
38	70.6	42.0	9.0
39	70.0	49.5	8.5
40	55.7	39.2	8.4
41	68.9	50.3	9.0
42	71.0	50.3	9.0
43	69.0	54.7	8.9
45	75.7	52.4	9.0
46	76.8	39.1	8.5
47	70.2	40.8	9.0
48	79.3	42.0	9.0
49	74.8	50.4	9.0
50	79.5	43.8	9.0
51	73.7	45.8	8.9
52	78.2	53.0	8.9
53	57.9	41.6	8.7
55	65.6	38.7	8.0
56	69.0	40.2	9.0
58	65.6	35.6	9.0
59	73.9	44.7	8.5
62	81.0	51.1	9.0
63	63.1	42.6	8.9

[1] See context Table 2 for identification of single crosses.
[2] Rated from 1 to 9; 1 = the least, 9 = the most.

Appendix Table 2. Early maturity single cross[1] means for plant width (cm.), forage yield per plant (gr.) and selfed-seed yield per panicle (mgr.), 1962.

Single Cross	Width	Forage Yield	Selfed Seed Yield
37	79.5	71.70	115.3
38	64.2	34.80	71.3
39	76.4	61.60	17.0
40	65.5	40.20	55.0
41	80.1	71.00	28.1
42	71.2	48.40	108.7
43	80.9	73.80	61.8
45	74.4	66.30	72.7
46	61.2	34.60	75.4
47	69.2	43.85	82.3
48	69.2	39.10	45.0
49	79.0	63.60	131.6
50	68.1	48.90	156.7
51	69.4	53.20	125.1
52	71.8	51.70	134.2
53	63.4	43.90	45.8
55	63.3	41.32	55.0
56	67.7	52.40	75.0
58	56.1	20.70	27.9
59	68.0	39.40	66.1
62	75.0	65.70	191.4
63	65.1	40.60	84.7

[1] See context Table 2 for identification of single crosses.

Appendix Table 3. Intermediate maturity single cross[1] means for plant height (cm.) and maturity (rating)[2], 1962.

Single Cross	May 12 Height	August 19 Height	Maturity
1	26.95	36.65	6.15
2	31.00	36.70	5.70
3	30.30	41.60	6.20
4	27.90	48.20	5.90
5	27.60	33.80	5.90
6	25.30	28.50	5.80
7	27.95	38.15	6.05
8	37.00	40.10	6.80
9	35.80	35.70	6.20
10	22.10	35.00	5.80
11	22.80	36.20	5.80
12	28.40	34.50	6.20
13	20.30	32.65	5.85
14	37.90	46.20	7.00
15	30.70	29.00	5.90
16	15.55	30.55	5.30
17	39.40	41.40	6.40
18	33.00	35.70	6.70
19	27.50	30.20	5.80
20	36.70	41.30	6.80
21	22.40	33.80	5.70
22	21.70	32.05	5.55
23	23.60	32.50	5.80
24	25.90	37.40	5.80
25	28.50	24.70	6.40
26	25.80	21.90	5.00
27	23.80	22.60	5.80
28	19.90	27.00	5.60
29	28.50	23.20	6.20
30	23.60	32.60	5.85
31	20.70	34.90	5.40
32	24.40	32.60	5.90
33	28.70	42.50	6.00
34	25.00	37.70	5.70
35	31.40	47.60	6.90
36	22.10	35.50	5.90

[1] See context Table 2 for identification of single crosses.
[2] Rated from 1 to 9; 1 = the least, 9 = the most.

Appendix Table 4. Intermediate maturity single cross[1] means for plant width (cm.), forage yield per plant (gr.) and selfed-seed yield per panicle (mgr.), 1962.

Single Crosses	Width	Forage Yield	Selfed-Seed Yield
1	61.40	15.25	15.25
2	65.10	17.05	17.05
3	70.00	66.90	66.90
4	76.70	287.05	287.05
5	64.25	148.35	148.35
6	47.20	61.90	61.90
7	62.55	230.00	230.00
8	63.70	51.35	51.35
9	55.70	62.30	62.30
10	54.90	141.45	141.45
11	63.40	84.80	84.80
12	54.90	62.30	62.30
13	51.85	58.10	58.10
14	74.50	57.65	57.65
15	49.20	51.65	51.65
16	46.10	31.20	31.20
17	68.80	93.45	93.45
18	58.50	129.95	129.95
19	50.30	45.80	45.80
20	73.60	122.55	122.55
21	65.60	18.05	18.05
22	49.45	70.65	70.65
23	45.40	85.90	85.90
24	61.80	94.50	94.50
25	36.00	13.30	13.30
26	30.80	22.10	22.10
27	33.00	103.30	103.30
28	43.60	8.00	8.00
29	32.80	10.70	10.70
30	50.20	18.70	18.70
31	61.80	33.95	33.95
32	60.40	65.20	65.20
33	68.40	24.45	24.45
34	73.10	79.90	79.90
35	78.20	124.55	124.55
36	62.90	14.95	14.95

[1] See context Table 2 for identification of single crosses.

Appendix Table 5. Late maturity single cross[1] means for plant height (cm.) and maturity (rating)[2], 1962.

Single Cross	May 12 Height	August 19 Height	Maturity
66	43.6	45.7	7.6
67	32.8	38.5	6.3
68	36.3	37.3	6.7
69	51.1	44.7	8.1
71	21.8	30.3	6.0
73	22.1	32.1	6.3
74	10.6	30.4	4.6
76	13.0	31.3	5.1
77	29.5	40.1	6.1
78	29.4	35.1	6.1
79	25.7	47.6	5.9
80	26.1	36.8	6.5
81	23.2	40.3	5.8
82	20.4	33.5	5.9
83	14.2	39.2	5.2
84	19.4	34.2	6.1
85	30.6	36.2	6.5
86	19.5	31.7	5.5
87	23.2	42.5	5.6
88	23.8	36.1	5.7
89	18.4	30.9	5.4
90	18.5	21.2	5.4
91	33.7	31.1	6.7
92	14.6	34.2	5.6
93	32.0	36.3	6.3
94	24.1	32.9	5.8
95	28.2	35.4	6.0
96	19.4	34.1	5.7
97	22.6	41.0	5.7
101	16.4	26.5	5.8
102	23.5	40.4	5.9
105	25.1	38.1	6.1
106	48.4	35.3	7.7
107	28.1	32.8	6.4
108	33.2	33.7	5.8
109	22.1	34.4	5.5

[1] See context Table 2 for identification of single crosses.
[2] Rated from 1 to 9; 1 = the least, 9 = the most.

Appendix Table 6. Late maturity single cross[1] means for plant width (cm.), forage yield per plant (gr.) and selfed-seed yield per panicle (mgr.), 1962.

Single Cross	Width	Forage Yield	Selfed Seed Yield
66	73.5	57.80	87.90
67	60.6	43.40	81.65
68	56.2	31.30	127.30
69	73.0	52.80	112.60
71	51.5	21.10	201.10
73	50.4	20.80	83.05
74	46.8	15.97	10.40
76	54.0	22.55	47.30
77	60.2	28.70	29.05
78	56.9	25.90	94.65
79	76.8	47.20	65.45
80	57.5	28.20	18.15
81	72.1	47.40	30.35
82	57.1	21.60	66.85
83	60.5	27.90	7.80
84	59.5	31.00	22.10
85	57.1	28.10	35.90
86	55.4	24.50	25.40
87	72.9	42.40	30.55
88	57.5	22.50	52.40
89	56.7	20.40	25.20
90	37.0	8.30	26.60
91	48.8	17.00	42.45
92	58.6	26.60	57.70
93	60.7	30.20	75.30
94	54.0	23.00	126.00
95	62.7	36.70	70.70
96	56.1	27.90	32.35
97	67.6	49.10	40.25
101	43.1	13.00	67.75
102	68.5	44.50	22.80
105	59.1	34.60	27.05
106	50.7	23.00	50.90
107	55.5	30.90	82.50
108	56.5	29.10	62.40
109	53.0	19.90	46.95

[1] See context Table 2 for identification of single crosses.

Appendix Table 7. Early maturity parental[1] means across single crosses for plant height (cm.), maturity (rating)[2], plant width (cm.), forage yield per plant (gr.) and selfed seed yield per panicle (mgr.), 1962.

Parent	No. of Crosses	May 12 Height	August 19 Height	Maturity	Width	Forage	Selfed Seed
304	6	71.7	46.5	8.7	69.8	51.3	79.9
314	6	70.4	43.9	8.8	68.0	46.7	77.0
315	6	66.3	41.9	8.9	67.1	44.7	66.0
339	7	67.4	47.5	8.9	71.2	54.2	80.0
340	5	76.2	43.5	8.9	68.3	44.2	96.0
342	6	72.4	44.6	8.8	70.9	52.5	102.3
351	5	72.7	47.4	8.7	70.7	48.9	99.1
356	3	69.0	48.4	9.0	76.2	65.7	55.0

[1] See context Table 1 for identification of parents.

[2] Rated from 1 to 9; 1 = the least, 9 = the most.

Appendix Table 8. Intermediate maturity parental[1] means across single crosses for plant height (cm.), maturity (rating)[2], plant width (cm.), forage yield per plant (gr.) and selfed seed yield per panicle (mgr.), 1962.

Parent	No. of Crosses	May 12 Height	August 19 Height	Maturity	Width	Forage	Selfed Seed
296	8	26.3	36.7	6.0	64.5	35.5	63.1
298	8	25.1	28.7	5.8	44.7	15.7	26.9
299	8	31.2	36.7	6.4	58.9	27.6	81.1
311	8	27.8	34.7	5.8	56.6	25.2	98.3
329	8	26.4	35.8	6.0	58.1	22.2	93.2
359	8	27.8	34.6	6.1	58.1	24.9	127.8
366	8	26.7	32.5	5.9	53.2	19.4	45.7
368	8	25.2	36.9	5.9	59.1	21.1	49.3
374	8	28.5	36.3	5.9	60.8	29.4	66.3

[1] See context Table 1 for identification of parents.

[2] Rated from 1 to 9; 1 = the least, 9 = the most.

Appendix Table 9. Late maturity parental[1] means across single crosses for plant height (cm.), maturity (rating)[2], plant width (cm.), forage yield per plant (gr.) and selfed seed yield per panicle (mgr.), 1962.

Parent	No. of Crosses	May 12 Height	August 19 Height	Maturity	Width	Forage	Selfed Seed
309	5	46.7	22.0	35.5	5.8	59.6	34.2
310	8	67.7	30.1	34.9	6.2	56.5	28.4
326	8	36.6	21.4	32.7	5.7	55.4	23.7
327	9	34.0	21.8	37.0	5.9	61.0	32.2
331	7	76.9	39.5	38.4	7.1	60.0	36.2
364	5	83.1	22.0	30.1	6.0	50.8	22.1
370	6	40.2	22.2	35.2	5.6	58.0	29.0
372	9	72.3	23.0	33.9	5.8	54.1	23.6
379	7	61.6	26.5	41.1	6.0	65.8	37.8
380	8	65.2	27.4	36.9	6.2	60.6	31.5

[1] See context Table 1 for identification of parents.

[2] Rated from 1 to 9; 1 = the least, 9 = the most.

Appendix Table 10. Numerical example for the combining ability analysis of the self-seed yield per panicle (mgr.).

Notation used: (Tables 14 and 15)

$$p = 9$$

$$X_{i.} = \sum_{j \neq i} xij = 504.95,\ 215.50,\ \ldots\ldots,\ 530.80$$

$$X_{i.}^{2} = 504.95^{2} + \ldots\ldots\ldots + 530.80^{2} = 3,513,209.94$$

$$X_{..} = \sum\sum_{i<j} xij = 2,607.25$$

$$\sum\sum_{i<j} x^{2}ij = 14.95^{2} + \ldots\ldots\ldots 65.20^{2} + 13.30^{2} + \ldots\ldots\ldots$$
$$24.45^{2} + \ldots\ldots 66.90^{2} = 318,423.11$$

a) Sum of squares for general combining ability

$$SSg = \frac{1}{p-2} \sum_{i} X_{i.}^{2} - \frac{4}{p(p-2)} X_{..}^{2}$$

$$= \frac{1}{7} \times 3,513,209.94 - \frac{4}{63} \times 6,797,752.56$$

$$= 70,283.79$$

b) Sum of squares for specific combining ability

$$SSsp. = \sum\sum_{i<j} x_{ij}^{2} - \frac{1}{p-2} X_{i.}^{2} + \frac{2}{(p-1)(p-2)} X_{..}^{2}$$

$$= 318,423.11 - 501,887.13 + \frac{2}{56} \times 6,797,752.56$$

$$= 59,312.86$$

c) General combining ability effects

$$gi = \frac{1}{p(p-2)} (pXi. - 2X..)$$

Parent

$$296 = \frac{1}{63} (9 \times 504.95 - 2 \times 2,607.25) = -10.63$$

$$298 = \frac{1}{63} (9 \times 215.50 - 2 \times 2,607.25) = -51.98$$

d) Specific combining ability effects

$$S_{ij} = x_{ij} = \frac{1}{p-2} (Xi. + Xj.) + \frac{2}{(p-1)(p-2)} X..$$

Cross

$$296 \times 298 = 14.95 - \frac{1}{7} (504.95 + 215.50) + \frac{2}{8x7} \times 2,607.25 = 5.15$$