AN ABSTRACT OF THE THESIS OF

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Title: AN EXAMINATION OF SEEDLING VIGOR AND THE EFFECTS OF GENETIC DIVERSITY ON RESPONSE TO HETEROSIS IN TALL FESCUE (*FESTUCA ARUNDINACEA* SCHREB.)

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Response to heterosis for plant height, anthesis date, panicle number, seed yield, and fall vigor rating was determined in a tall fescue group selected for diverse morphology, origin, and anthesis date. Parents, single-cross progeny (SX), and first generation selfed progeny (S_1) were included in the study.

Each experimental plot consisted of 14 plants spaced three feet apart in a row with four feet between rows. Plants were established in the field in September, 1969, in a randomized block design with four replications. Data were collected during the summer and fall of 1970.

Single-cross progeny were superior to parents with the exception of seed yield, with parents above S_1 progeny except in plant height.

Single-crosses averaged 15.36, 2.60, 28.21, 24.79, and 23.04

percent above the mid-parent for plant height, early anthesis date, panicle number, seed yield, and fall vigor rating respectively. Single-crosses averaged 5.85 and 10.27 percent above the high-parent for panicle number and fall vigor rating respectively.

Crosses between maturity groups resulted in the greatest heterosis above the mid-parent for all characteristics and above the high-parent for panicle number (117.50 percent of the high-parent). Early x early single-crosses were tallest (106.49 percent of the high-parent) and had the most vegetative vigor (115.36 percent of the high-parent).

Indications are that crosses between parents of diverse morphology and origin result in a greater expression of heterosis than crosses among similar parents. Diverse anthesis date appears to increase response to heterosis.

Vigor and associations among vigor characteristics were determined from single-cross and S_1 seed and seedlings. Respiration, germination, root and shoot growth, rate of growth, and unit growth characteristics were measured using a Gilson differential respirometer and a seed germinator.

For most seed and seedling vigor characteristics S_1's and SX's were very similar. Early S_1 and early x early SX groups were consistently more vigorous than late S_1 and late x late SX groups with the early x late SX group intermediate between early x early and late x late SX groups for all seedling vigor characteristics.

Root length and vigor index were two of the better indicators of early seedling vigor, with vigor index favored because it takes less time to measure and requires less space. Selection on the basis of vigor index should be an effective laboratory method of screening for higher seedling vigor in tall fescue.

There was a significant association between most seed and seedling vigor characteristics in SX's and S_1's, and most seed and seedling vigor characteristics were associated with from one to three mature plant characteristics, most often fall vigor rating.

Three methods of selection for high and low seedling vigor (seed weight, head selection on shoot length, and emergence from deep seeding) resulted in small changes in seed weight and vigor index of progeny.

Clones from a population with low seed weight and seedling vigor were self-pollinated and topcrossed to a source with high seed weight and seedling vigor. Positive associations between topcrosses and S_1's for seed weight and vigor index suggests a lack of appreciable heterosis for these characteristics.

The association of forage and seed yield was studied in duplicate populations of parents and five progeny groups. These were: first generation selfed (S_1), open-pollinated OP), polycross (PX), single-cross (SX), and selfed single-cross (F_2). Nurseries were planted in a randomized block design with four replications, with harvests made during the spring and summer of 1969.

There were significant associations of forage and seed yield in four progeny groups with no association in parents and polycross progeny. The highest correlation occurred in the S_1 progeny ($r = .794$).

High forage and seed yields in certain OP, PX, and SX progenies indicate the possibility of breeding for both characteristics simultaneously.

An Examination of Seedling Vigor and the Effects of Genetic Diversity on Response to Heterosis in Tall Fescue (*Festuca Arundinacea* Schreb.)

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INTRODUCTION

The phenomenon heterosis, although not thoroughly explained genetically, has been responsible for large increases in yield of several important crop species. Studies in tall fescue have revealed little or no heterosis, perhaps because breeders with the ultimate objective of synthetic variety development, have selected parent material on the basis of similarities. Genetic diversity has been shown to be closely associated with response to heterosis in other species, therefore diversity should also give increased heterosis in tall fescue.

The ability of the seed to germinate rapidly and the seedling to grow rapidly are important characteristics desired in all varieties used for forage and turf. Numerous techniques have been employed to screen for higher seedling vigor, some of which are effective in certain species and not in others. Methods of breeding for higher seedling vigor are also varied. Information is needed on effective methods of screening and breeding for higher seedling vigor of forage and turf species.

The primary objective of most forage breeding programs is high forage yield, but an adequate seed yield is also important.

Breeders need to know what effect selection for higher forage yield using various types of progeny tests will have on seed production.

The objectives of this study were:

1. Determine if increased diversity of morphology, origin, and anthesis date resulted in a greater response to heterosis in tall fescue.
2. Determine differences in vigor among single-cross and first generation selfed seeds and seedlings and to compare techniques for measuring seedling vigor.
3. Determine the relationships among seed and seedling vigor characteristics and between seed and seedling characteristics and plant height, anthesis date, panicle number, seed yield, and fall vigor rating.
4. Evaluate one cycle of selection for high and low seedling vigor by three methods of selection (seed weight, head selection on shoot length, and emergence from deep seeding).
5. Study the breeding behavior of seedling vigor by way of topcross and S_1 performance.
6. Study the association of forage and seed yield of tall fescue as influenced by type of progeny test.

LITERATURE REVIEW

Heterosis

Heterosis in numerous important crop plants is well documented in the literature. Although there is not an adequate genetic interpretation of heterosis, plant breeders have effectively used it to obtain higher yields.

Richey (1922) summarized 244 comparisons made in corn prior to 1920. He found that 84.4 percent of all F_1's tested were higher yielding than the mid-parent while 55.7 percent of the F_1's yielded more than the high-parent. Since 1920, many workers have reported similar degrees of heterosis in corn (Moll, Salhuana and Robinson, 1962; Paterniani and Lonnquist, 1963; Moll *et al.*, 1965; Troyer and Hallauer, 1968). For more than 30 years hybrid corn varieties have been used to facilitate the expression of heterosis.

Briggle (1963) reviewed a large number of examples of heterosis in wheat crosses. Gyawali, Qualset and Yamazaki (1968) observed that the average yield of 21 winter hybrids was 24 percent greater than the better parent of each cross. Twenty-one winter wheat crosses studied by Peterson (1970) yielded from 84 to 172 percent of the high-parent and averaged 121 percent of the high-parent.

The average yield of barley hybrids studied by Suneson and Riddle (1944) was 20 percent above the mid-parent. Later Suneson

(1962) suggested that earlier yield estimates of hybrid barley were too conservative and that hybrids have from 30 to 50 percent greater productivity than the best parent. Upadhyaya and Rasmusson (1967) found average heterosis for yield to be 21.5 and 9.1 percent above the mid-parent and high-parent respectively. Their best barley hybrids were 22 and 28 percent above the higher parent. Severson and Rasmusson (1968) found that the degree of heterosis exhibited by their barley hybrids was influenced greatly by seeding rate, and warned that space planting can lead to erroneous conclusions concerning the performance of hybrids commercially. Plant spacings of 2.5, 7.5, 15.0, and 22.5 cm resulted in 3.2, 16.7, 17.3, and 22.5 percent heterosis beyond the mid-parent respectively.

Petr and Frey (1967) reported that all of the oat hybrids they tested exceeded the high-parent by from 10 to 30 percent for yield with average heterosis of 12 and 13 percent above the high-parent for yield and panicle number.

Marani (1963, 1968) is one of several workers who have observed a large degree of heterosis for yield and yield components in cotton.

The best five of 31 alfalfa hybrids tested produced 23 percent more forage than the highest yielding commercial variety (Tysdal and Kiesselbach, 1944). Wilsie (1958) found a striking degree of heterosis for forage yield of alfalfa with two F_1's 43 and 83 percent above the high-parent.

The literature reveals almost nothing of the nature of heterosis in forage grass species. Using the data of Echeverri (1964) who studied eight tall fescue parents and their 28 single-crosses representing an early maturing group, it was shown that heterosis was seldom expressed. For plant height, maturity rating, culms per plant, and seed yield the F_1's averaged 6.7, 4.8, 3.0, and 20.7 percent above the parents. The heterosis observed for seed yield was almost entirely a result of four crosses involving low x low seed producers. These four crosses produced 82 to 214 percent more seed than the high parents.

Matheson (1965) studied the breeding behavior of intermediate and late maturing groups of tall fescue and reported that little or no heterosis was expressed for plant width, plant height, leaf length, plant density or forage yield. Thomas (1967) investigated seed yield and its components in early and intermediate maturity groups of tall fescue. Using his data it was found that for tiller number and seed yield the 28 single-crosses of the early maturing group and the 36 single-crosses of the intermediate maturing group averaged lower than their parents over three years. Single-cross and parent averages for seed weight differed by less than one percent. Only one of the 64 single-crosses had significantly more tillers than the high-parent and this was during only one of three years of testing. No single-cross was significantly higher than the high-parent for seed yield, and only two single-crosses had seed significantly heavier than the high-parent. The parents for these studies (Thomas, 1967; Matheson, 1963; Echeverri, 1964) were chosen on the basis of low self-fertility, high seed and forage potential, nutritive value, and similar maturity date.

Diversity and Heterosis

The demonstration of heterosis indicates some degree of genetic diversity between the parents (Sprague, 1966). It is logical to reason then that with increased genetic diversity we should expect higher levels of heterosis. Genetic diversity of varieties, races, and species have probably arisen through geographical isolation accompanied by a combination of genetic shift and selection in different environments. Therefore the degree of geographical separation and ancestral relationship should be an indication of genetic diversity (Moll, Salhuana and Robinson, 1962).

Moll, Salhuana and Robinson (1962) crossed corn varieties from the midwest, southeast, and Puerto Rico in all combinations. The average within region hybrids yielded four percent above the mid-parent while between region crosses were 24 percent better than the mid-parent. Their best single-crosses were between southeastern and Puerto Rican varieties. Interracial crosses of Paterniani and

Lonnquist (1963) resulted in a higher percentage of corn hybrids that exceeded the mid-parent and high-parent in yield than crosses involving more closely related material studied by Richey (1922) and Lonnquist and Gardner (1961). Moll et al. (1965) also found that heterosis was associated with diversity of parents in corn, but that extreme divergence sometimes results in reduced heterosis.

Marani (1963, 1968) observed that interspecific crosses in cotton resulted in greater heterosis for yield and seed size than did intraspecific crosses. Wilsie (1958) found more heterosis for yield in crosses involving alfalfa plants with diverse growth habit. Sriwatanapongse and Wilsie (1968) noted that the largest heterotic response for forage yield and general vigor of alfalfa was obtained in interspecific crosses and that heterosis was greater in intervariety crosses than in crosses within varieties.

Crosses between early and late maturing wheat varieties resulted in greater expression of heterosis than crosses within early and late maturing groups (Gyawali, Qualset and Yamazaki, 1968).

Seedling Vigor

Seedling vigor takes on a slightly different meaning for different workers. In establishing range and other dryland grasses seedling vigor may mean the ability to emerge from deep planting and to survive adverse conditions by rapid root development. Those working with forage legumes may be concerned with the competing ability of young seedlings with weeds (Draper and Wilsie, 1959). The turf grass breeder looks for rapid germination and rapid extension of the shoot, while cereal workers may consider seedling vigor as the ability to establish a uniform stand (Demirlicakmak et al., 1963). All would probably agree however that seedling vigor is a result of the sum total of all seed attributes which favor rapid and uniform stand establishment (Delouche and Caldwell, 1960).

Methods of testing for seedling vigor are many and varied. Maguire (1962) developed a test in which the number of seeds germinated at each count is divided by the number of days they have been exposed to germination conditions. The figures obtained at each counting date are then summed to give the speed of germination. Lawrence (1963) used speed of germination to evaluate clonal lines of Russian wild ryegrass for seedling vigor. Twamley (1969) used a visual speed of germination rating in studying seedling vigor in birdsfoot trefoil. Tucker and Wright (1965) developed the regression index method for estimating rapidity of germination, which they described as a simple, direct, easily analyzed and computed method that can be related directly to time.

Kittock and Law (1968) scored vigor of 100-seed lots of various sizes and ages of wheat seeds by multiplying daily emergence data by the reciprocal of days to emerge. Others who have used rate of emergence as a criterion of seedling vigor are Allen and Donnelly (1965) working with vetch, Kittock and Patterson (1962) with several dryland grasses, Kneebone and Cremer (1955) on native grasses and Tossell (1960) in smooth bromegrass.

Several workers have studied emergence as influenced by depth of planting. Beveridge and Wilsie (1959) in seeding alfalfa 0.5, 1.0, and 1.5 inches deep found that the number of seedlings emerged decreased with increasing depth. Emergence rate was slower from deeper plantings in the greenhouse but not in the field. Lawrence (1963) measured seedling vigor on the basis of emergence from three depths of seeding in Russian wild ryegrass. At the 1.5 inch depth, emergence was significantly associated with seed size. Rogler (1954) planted crested wheatgrass at six depths, from one-half to three inches, and found the correlation of emergence rate with seed size increased with each increase in depth of planting, being .92 at 3.0 inches in the greenhouse. Emergence from a 3.0 inch depth and seed weight were strongly associated in intermediate wheatgrass (r = .80) (Hunt and Miller, 1965), but Demirlicakmak, Kaufman and Johnson (1963) found no effect of seed size on emergence in barley.

Seedling weight has been used by some as a more direct measure of seedling vigor. Dry weight of the entire alfalfa plant 28 days after seeding was used as a greenhouse seedling vigor rating by Beveridge and Wilsie (1959). They determined field seedling vigor by the dry weight of the above ground portion of the plant 56 days after seeding. Harkness (1965) used shoot and root weights to measure early seedling growth of Italian ryegrass, while Thomas (1966) measured shoot weight in perennial ryegrass. Kneebone and Cremer (1955) used the dry weight of 100 seedlings of native grass species to estimate seedling vigor. Dry weight of 100 plants 35 days after seeding was significantly correlated with 100-seed weight in two years (r = .775, .745) of testing smooth bromegrass (Peace, 1953). Shibles and MacDonald (1962), Stickler and Wassom (1963), and Twamley (1969) determined seedling vigor of birdsfoot trefoil by the dry weight of seedlings, and found that it bore a direct relationship to seed size.

Voigt and Brown (1969) used shoot length as the criterion for seedling vigor in side-oats grama as did Kneebone and Cremer (1955) with this and several other native grass species. Maguire (1968) measured shoot growth of Kentucky bluegrass varieties, and also computed daily growth rate of the shoot. Tossell (1960) estimated vigor of smooth bromegrass progenies by the height of the tallest 20 percent of the seedlings in a pot, while Henson and Tayman (1961) measured plant height of birdsfoot trefoil 30 days after seeding.

Hunt and Miller (1965) found a high correlation (r = .77) between seedling height and seed weight of intermediate wheatgrass. In Russian wild ryegrass relative root growth in glass tubes was used to determine seedling vigor (Lawrence, 1963). Woodstock and Combs (1964) found that shoot growth of corn between two and five days after germination seemed to be a better measure of seedling vigor than root growth, embryo axis, or increase in seedling fresh weight.

Cotyledon area was related to seedling vigor and seed size in birdsfoot trefoil (Shibles and MacDonald, 1962). Harper and Obeid (1967) measured leaf area of developing flax seedlings as did Thomas (1966) in perennial ryegrass.

Woodstock (1965) compared respiration of corn seedlings at different times prior to germination with subsequent root and shoot growth. Oxygen uptake was strongly associated with both root and shoot growth, with the highest correlations 27-29 hours after start of imbibition. Woodstock and Grabe (1967) noted that the highest correlations of oxygen uptake with shoot growth of corn occurred at times of maximum respiration. Carbon dioxide evolution was not as highly associated with shoot growth as was oxygen uptake, and the correlation of respiration quotient with shoot growth was -.97. Maguire (1968) used oxygen consumption as a seedling vigor criterion for Kentucky bluegrass varieties.

Kittock and Law (1968) compared respiration, and tetrazolium chloride reduction of germinating wheat seeds to seedling vigor as measured by rate of emergence and shoot dry weight. They concluded that respiration mainly measures the non-genetic factors of seedling vigor. Tetrazolium chloride reduction was significantly correlated with seedling vigor but the authors were not convinced that this fast and simple technique would consistently and accurately measure differences in seedling vigor.

Breeding for Increased Seedling Vigor

There are three ways breeders can attempt to improve seedling vigor. These are by selecting: 1) for a correlated character, e.g. seed size, 2) for a possible component of seedling vigor, e.g. speed of germination, 3) for seedling vigor *per se* (Voigt and Brown, 1969).

Selection for heavy or large seed is one of the easier and most often used methods for improving seedling vigor. Christie and Kalton (1960) with one cycle of divergent recurrent selection for high and low seed weight of smooth bromegrass almost doubled the range. They concluded that recurrent selection for clones producing heavy seeds would be feasible for improving seedling vigor of the species. Tossell (1960) also came to the conclusion that in breeding for early seedling vigor in smooth bromegrass, the most rapid progress could be made by screening material on the basis of seed weight.

Lawrence (1963) suggested that the best way to increase seedling vigor of Russian wild ryegrass was to select large seeded lines and plant them deep, while Slinkard (1963b) suggested measuring plumule length of larger seeded lines to evaluate seedling vigor.

Data of Rogler (1954) indicated that the direct approach for increasing seedling vigor of crested wheatgrass is the selection of large or heavy seeded types. In practice however, genotypes of heavier seeded phenotypes were relatively less effective in producing heavier seeded progeny than those of lighter seeded phenotypes (Schaaf and Rogler, 1963). They concluded that seed set must be taken into consideration when selecting for high seed weight in this species.

Draper and Wilsie (1965), in three cycles of recurrent selection for large seed were able to increase seed size of Viking and Empire birdsfoot trefoil by an average of 20 and 6.25 percent per generation respectively. Kittock and Patterson (1962) working with several dry-land grasses warned that location of seed on the inflorescence was probably a bigger factor in determining seed weight than was genetic variability.

One cycle of selection for vigorous seedlings of side-oats grama gave improved seedling vigor (Kneebone, 1956). Voigt and Brown (1969) using phenotypic recurrent selection for robust seedlings in this species, improved height of seedlings established by 24 percent and stand count by 35 percent. Schaaf and Rogler (1963) on the basis of performance of two clone synthetics concluded that seedling vigor probably responds to specific combining ability in crested wheatgrass.

Heritability of seed weight in intermediate wheatgrass as estimated by parent progeny regression using topcross progeny was a low .36 (Slinkard, 1963a). Thomas (1967) found seed weight of tall fescue to be more highly heritable. Average heritability over three years and six methods of estimation in early and intermediate maturing groups was .506 and .622 respectively.

Association of Forage and Seed Yield

In developing new varieties of forage crops, breeders normally place the greatest emphasis on forage yield. However since a stable and economical supply of seed is necessary for the maximum utilization of a variety, attention must also be directed to its seed production potential. Obtaining high forage and high seed yield in the same variety is often a problem but few studies have reported on the relationship between the two.

Schaaf, Rogler and Lorenz (1962) noted a very low average correlation of .077 between forage and seed yield of crested wheatgrass. Correlation coefficients in their study varied from -.39 to .38 and were never significant in six years of testing varieties, polycross progenies, and open-pollinated progenies. McDonald, Kalton and Weiss (1952) working with S_1 and OP progenies of bromegrass found that a visual score of panicle number was significantly associated with forage yield. Knowles (1955) had several first generation bromegrass synthetics which were significantly higher in forage and seed yield than commercial check varieties.

Bolton (1948) selected alfalfa clones for high seed yield and was able to maintain acceptable levels of forage yield in several of the single-cross progenies. Melton (1969) in studies of polycross and single-cross progenies of alfalfa found that forage yield and seed yield were significantly correlated (r = .54), and that it was possible to obtain both traits in the same single-cross. For example, the best of 36 single-crosses for forage yield ranked second in seed yield. Both of these alfalfa studies indicated that large increases in seed yield could be made while maintaining or increasing forage yield.

Burton and De Vane (1953) found no relationship between seed yield and forage yield in tall fescue and they felt that if selection pressure was applied for high seed production it would be acquired at the expense of forage yield and vice versa. This was because clones producing the highest seed yields were only average in forage yield and clones producing the most forage were below average seed producers. Echeverri (1964) also found a lack of relation between seed and forage yield in early maturing tall fescue (r = -.11). He was working with 28 single-crosses and took forage yield on regrowth two months after seed harvest.

Cowan (1952) noted a significant correlation (r = .30, n = 958) between forage and seed yield of tall fescue. Although this association was statistically significant it is of little predictive value biologically. In 20 open-pollinated progenies of tall fescue the correlation of seed yield with pasture yield (clipped when plots were 8-9 inches in height) and hay yield (cut in full bloom with two aftermath harvests) was a significant .471 in each case (Cowan, 1955). His data indicated the possibility of selecting for high forage and high seed yield in the same clone because certain clones produced progenies which were superior in both traits.

MATERIALS AND METHODS

Source of Material

Seedling Vigor and Heterosis Phases

The nine parent clones were selected from a plant introduction nursery on the basis of diverse morphology, anthesis date and origin. The identity and description of parent clones are presented in Table 1. Parent clones were lifted from the introduction nursery, vegetatively propagated, and established in a single-cross nursery in July 1966.

On December 26, 1968 four plants of each genotype in each cross were lifted, clipped and transplanted to 10" pulp pots in the greenhouse. Temperature was regulated to 68-72° F with artificial lighting used to provide a 16 hour day. When panicles had almost completely emerged from the boot, the earlier flowering genotypes were moved to a cold chamber and held at 38° F. When the later flowering genotypes had panicles completely emerged from the boot, the early genotypes were returned to the greenhouse. This was done to facilitate crossing by mutual pollination. Minor adjustments in anthesis of genotypes were made by moving more advanced plants to a corner of the greenhouse where there was lower light intensity. Single-cross (SX) seed was obtained by bagging panicles of the parent clones together just prior to anthesis. Parchment bags measuring 3" x 5" x 17" were used to enclose the panicles.

Table 1. Description of parental clones used in seedling vigor and heterosis study.

Clone	Origin	P.I. number	Anthesis date[1]	Self-fertility[2]	Plant height[3]	Leaf width[3]	Plant width[3]	Panicle number[3]
<u>Early</u>								
P_1	Switzerland	234-906	May 15	45.00	1	8	2	2
P_2	Yugoslavia	251-583	" 18	45.80	4	5	5	2
P_3	Spain	234-047	" 21	9.05	3	5	4	4
P_4	Greece	199-249	" 27	29.43	3	5	4	5
P_5	Uruguay	203-728	" 29	29.68	2	5	3	7
<u>Late</u>								
P_7	Poland	274-617	June 10	14.30	3	4	5	6
P_8	Yugoslavia	253-311	" 15	21.05	7	2	9	5
P_9	Turkey	174-209	" 28	3.63	7	9	10	10
P_{10}	Switzerland	234-885	" 28	29.33	8	5	8	5

[1] 1967

[2] Weight of selfed seed from three five-panicle samples divided by seed weight of 15 open-pollinated panicles.

[3] Phenotypic rating 1-10 June 4, 1969. 1 represents tallest plant, finest leaves, widest plant, most panicles.

Three types of single-crosses were made with respect to anthesis date, with three single-crosses in each type. These were early x early, late x late, and early x late. First generation selfed (S_1) seed was obtained by bagging panicles of the parent clones before anthesis. After conducting seedling vigor tests, seedlings were planted in 2-1/4" x 2-1/4" x 2-1/4" "Jiffy-strips" and held in the greenhouse. The parent clones were vegetatively propagated and held in the same manner.

Forage and Seed Yield Nurseries

Progeny were derived from nine parent clones of tall fescue with intermediate maturity date. The nine parental clones were selected from 9,000 spaced plants on the basis of self-sterility, seed and forage yield potential based on phenotypic ratings, nutritive value on the basis of crude protein and chromogen content, and for maturity date. Table 2 identifies these parental clones.

Each nursery (forage phase and seed phase) contained parental clones, single-cross progeny (SX), open-pollinated progeny (OP), first generation selfed-progeny (S_1), selfed single-cross progeny (F_2), and polycross progeny (PX). The parent clones were vegetatively propagated to enable establishment of 36 crossing blocks. Each crossing block consisted of two rows with eight propagules per row and six inches between propagules.

Table 2. Identification[1] of the intermediate maturing parent clones used in group I of the progeny testing nurseries.

Genotype	Flowering date May[2]	Chromogen[3]	Percent crude protein[3]	Grams seed yield[4]	Appearance forage[5]	Percent self-fertility[6]	Origin
			Intermediate maturity (5/21 to 5/25)				
296	24	132	10.52	3.53	5, 4, 5	15.5	Alta
298	22	132	10.05	3.44	5, 4, 6	2.1	Alta
299	22	162	9.98	4.42	4, 3, 5	9.5	Alta
311	23	151	8.70	3.35	6, 3, 5	5.5	K-31
329	23	135	9.05	3.00	4, 4, 4	4.6	K-31
359	24	127	10.30	3.04	4, 4, 4	7.6	Mo. #1
366	25	147	11.49	2.60	4, 4, 5	5.6	Mo. #2
368	22	125	8.99	4.04	5, 4, 7	7.4	Mo. #3
374	23	138	8.76	2.18	5, 3, 4	7.5	Mo. #3

[1] Forage breeding project annual report, p. 51, 1960, Farm Crops Department, Oregon State University.
[2] 1957-58 average.
[3] Clippings made 7/10/57 through 7/24/57 at similar maturity stages.
[4] Five panicle samples, 1955.
[5] Phenotypic rating 1-7, made early, intermediate and late in summar; 7 is most desirable.
[6] Self-pollinated seed weight divided by open-pollinated seed weight times 100.

The SX seed was obtained by bagging panicles of the two parent clones together in all possible combinations before anthesis. The OP seed came from panicles of parental clones unbagged, and the S_1 seed came from panicles of the parent clones bagged prior to anthesis. The F_2 seed was obtained by bagging panicles of SX plants prior to anthesis. Each F_2 consisted of equal amounts of selfed-seed from five F_1 plants of the SX. Some crosses did not produce sufficient selfed seed and were not included in the nurseries. The PX seed was obtained from an isolated PX nursery consisting of ten replications in a randomized block design.

In order to break dormancy the SX, OP, PX, S_1, and F_2 seeds were planted in trays filled with perlite, watered, and held for five days at 38° F. After germination the seedlings were transplanted to 2" x 2" x 3" plant-bands and held in the greenhouse until taken to the field. Vegetative cuttings of the parent plants and seedlings of the check variety, Alta, were also established in plant bands.

Seedling Vigor Selections

All plants used to study methods of phenotypic selection for increased and decreased seedling vigor were derived from Syn-2 seed of the variety Fortune[1] which is described as having poor

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[1] Described in the 1968 annual report of the Forage Breeding Project, Oregon State University. p. 75-78.

seedling vigor.

Method A. Seeds for selection on the basis of panicle performance were collected by harvesting one panicle from each of 80 plants at random in the Fortune breeders block on July 3, 1968. This field consisted of spaced planted plants from Syn-1 seed. Seed of the 80 seed heads was divided into two 100-seed samples, weighed and then planted in 3" plastic pots in soil in the greenhouse on October 6, 1968. On the basis of plumule length, nine days after planting, seedlings of the six most vigorous and six least vigorous heads were selected to constitute two populations. Each population contained 300 plants consisting of 50 seedlings from each of the six heads. After selection seedlings were transplanted to 2-1/4" x 2-1/4" x 2-1/4" "Jiffy-strips" and held in the greenhouse.

Method B. Selection on the basis of seed weight was made by separating 700 grams of Fortune breeders seed (1968 crop) into the heaviest and lightest five gram fractions. Seeds were germinated in perlite and 300 seedlings from each fraction were transplanted to "Jiffy-strips" and held in the greenhouse. Seedlings from heavy and light seeds represented selection for high and low seedling vigor respectively.

Method C. Selection on the basis of ability to emerge from deep seeding was accomplished by planting 12 grams of Fortune breeders seed 3" deep in flats containing soil. Approximately 500 seedlings emerged and the most vigorous 300 were selected to constitute a population with high seedling vigor. Seed from the same source was planted 1/2" deep in perlite and the 300 smallest seedlings were selected to constitute a population thought to have low seedling vigor. Seedlings from both populations were transplanted to "Jiffy-strips" and held in the greenhouse.

Seedlings selected by methods A and B were transplanted to the Hyslop Agronomy Farm, Corvallis, Oregon on March 26, 1969, with seedlings selected by method C transplanted on August 12, 1969. Seedlings selected by method A were randomized within the plots so that seedlings derived from the same head would not all be planted together. Plants were set on 1'6" centers resulting in six plots measuring 8' x 20'. There were 16' between plots in one direction and 12' in the other direction. The populations established in August were irrigated several times using a hose and sprinkler from nearby turf plots, until sufficient moisture was available from rainfall. The six populations contained a total of 1800 plants.

In October, 1969, cereal rye was seeded between and around the plots to help serve as a pollination barrier. In order to insure isolation, muslin cages were erected over each plot. The frames were constructed by nailing three rows of 1" x 4" boards (bottom, middle and top) to six 4" x 4" x 5' standards set in the ground two feet. Unbleached muslin (56 x 64 threads/inch) was then stretched and stapled over the frames before anthesis (May 26). To insure pollination compressed air was released in each cage from inside each end for 14 days after anthesis began.

Air temperature inside the cages averaged six degrees above outside temperature. On a clear day when light intensity was 12,000 foot candles outside, 5,200 foot candles were received inside the cage. The amounts of blue, red, and far-red light received in the cage as a percentage received in direct sunlight were 64, 38, and 34 percent, respectively. The cages were removed on July 9 and the panicles cut with a hand sickle on July 13. The panicles were threshed in a plot thresher and the seeds cleaned with a Clipper cleaner.

Topcross

Twenty-five clones were selected at random from the Fortune breeders block and transplanted on March 4, 1969 throughout a large nursery made up of eight clones of the variety Fawn, which is known to possess high seedling vigor. First generation selfed (S_1) seed was obtained from each Fortune clone by bagging 15 panicles prior to anthesis. Topcross (TX) seed was harvested from panicles bagged after anthesis. The Fortune clones were fairly small and there was an insufficient quantity of S_1 seed from several clones so all clones were dug and transplanted to 10'' pulp pots on December 22, 1969.

Clones were then placed in the greenhouse at 68-72° F with artificial lights providing a 16 hour day. Prior to anthesis, panicles were bagged. All panicles were hand threshed and seed cleaned with a hand screen and South Dakota blower. Field and greenhouse produced S_1 seed was kept separate.

Establishment

Heterosis Nursery

Seedlings along with vegetative propagules were transplanted to Hyslop Agronomy Farm, Corvallis, Oregon on September 23, 1969. The nursery was planted in a randomized block design with four replications. Each plot consisted of a row of 14 plants spaced three feet apart with four feet between rows. Due to an insufficient amount of seed, the S_1 of parent clone P_9 was not established and only one replication of the S_1 of parent clone P_7 was established. Extra plants from the greenhouse were used to establish border rows around the field. Plants were watered with the farm water tank until sufficient moisture was available from rainfall. The nursery contained 1,418 plants excluding border rows.

Forage and Seed Yield Nurseries

Seedlings and vegetative propagules were transplanted to the Hyslop Agronomy Farm, Corvallis, Oregon in early October 1962.

Missing and dead plants were replaced in late October. Each nursery was planted in a randomized block design with four replications organized into 17 ranges and 45 rows per range. Each plot consisted of a row of ten plants spaced one foot apart with three feet between rows. Two orchardgrass plants were planted at the end of each row to identify ranges and to offset border effects. Extra tall fescue plants were used for border rows around the field. A total of 8, 080 plants were used in the two nurseries excluding border plants.

Maintenance

Weeds in all nurseries were controlled by periodic hoeing with tillage between the rows where possible.

Fertilizer (45-0-0) was applied to the heterosis nursery at the rate of 60 pounds per acre on November 29, 1969. On April 1, 1970, 40 pounds per acre each of 45-0-0 and 16-20-0 fertilizer was applied. Aphids were controlled on April 15 by spraying with Malathion.

Fertilizer was applied to the forage and seed yield nurseries at the rate of 30 pounds of nitrogen per acre before establishment. Nitrogen was also applied in December 1963 at the rate of 30 pounds per acre and in October 1964 and 1968 at the rate of 80 pounds per acre. Beginning in 1963 Diuron was applied each year in the fall at the rate of three pounds of active material per acre. After the first forage harvest the forage nursery was cut to a uniform height of 3" with a flail type harvester.

The populations selected for high and low seedling vigor and the rye pollination barrier were fertilized with 80 pounds per acre of 16-20-0 on March 28, 1970.

Measurements

Seed Respiration

Four 40-seed samples of the nine SX's, eight S_1's, and the check variety Fawn were weighed to the nearest one-tenth mg. Seeds were placed in fine screen wire containers with stoppers and soaked for five minutes in a 10 percent solution of "Joy" detergent. After rinsing for five minutes in running tap water seeds were surface sterilized in a one percent solution of chlorox after which seeds were again rinsed with running tap water for five minutes. Seeds were then wrapped in moist paper towels and held at 38° F for five days for stratification. After stratification samples were placed in petri dishes and held 47 hours in a germinator with alternating temperature (16 hours at 59° F, eight hours at 77° F). Preliminary experiments indicated that surface sterilization had no adverse effect on respiration and that without surface sterilization, microorganisms could contribute a significant amount to total respiration. It was also found that after stratification tall fescue seeds reached near-maximum levels of respiration at 46-48 hours after exposure to germination conditions. Forty seeds were then placed in 15 ml double armed Warburg flasks, and .75 ml of distilled water added to the flask compartment. In flasks measuring oxygen exchange 0.2 ml 4N KOH was added to the center well. A filter paper was placed in the center well to increase the CO_2 absorbing area of the KOH and the lip of the center well was coated with a mixture of vaseline and lanoline to prevent KOH from creeping over the sides of the well and contaminating the flask compartment. Oxygen consumption and CO_2 evolution were measured on duplicate samples using a Gilson Differential Respirometer with a water bath temperature of 77° F. Water was placed in two flasks, and attached at the first and last positions and used as thermal barometers to indicate pressure changes other than gas exchange. Experiments were run for 30 minutes after which the seeds were removed from the flask. Measurements recorded were:

1. Oxygen uptake, expressed as the average of two samples in µl of gas per 40 seeds per 30 minutes.
2. Oxygen uptake, adjusted to 100% germination.
3. Oxygen uptake, adjusted to 100% germination and a common seed weight (Fawn).
4. CO_2 evolution, expressed as the average of two samples in µl of gas per 40 seeds per 30 minutes.
5. CO_2 evolution, adjusted to 100% germination.
6. CO_2 evolution, adjusted to 100% germination and common

seed weight.

7. Respiration quotient (RQ), expressed as the average of two samples, computed by dividing CO_2 evloution by oxygen uptake.

Seedling Vigor

Twenty-five of the 40 seeds from each flask were chosen at random and placed in 9-1/2" x 6" plastic germination boxes containing seed germination blotting paper overlaid with Whatman filter paper. The germination boxes were placed on a 45^{o} angle in a germinator with alternating temperature (16 hours at 59^{o} F, eight hours at 77^{o} F), and low light intensity (100 foot candles). Seedlings were germinated on an angle because the roots grow downward which aids in making measurements. Measurements recorded were:

1. Percent germination, number of germinated seeds, expressed in percent of number attempted (100).
2. Vigor index expressed as

$$\frac{\text{Number of seeds germinated to day 4}}{4} +$$

$$\frac{\text{Number of additional seeds germinated by day 7}}{7} +$$

$$\frac{\text{Number of additional seeds germinated by day 9}}{9},$$

therefore higher numbers indicate more vigor.

3. Root length at four days, expressed as the average length of

the root in centimeters of seeds germinated by the fourth day.

4. Root length at seven days, expressed as the average length of the root in centimeters of seeds germinated by the seventh day.

5. Root length at nine days, expressed as the average length of the root in centimeters of seeds germinated by the ninth day.

6. Shoot length at four days, expressed as the average length of the shoot in centimeters of seeds germinated by the fourth day.

7. Shoot length at seven days, expressed as the average length of the shoot in centimeters of seeds germinated by the seventh day.

8. Shoot length at nine days, expressed as the average length of the shoot in centimeters of seeds germinated by the ninth day.

9. Length of total axis at four days, expressed as the average length of the root plus shoot in centimeters of seeds germinated by the fourth day.

10. Length of total axis at seven days, expressed as the average length of the root plus shoot in centimeters of seeds germinated by the seventh day.

11. Length of total axis at nine days, expressed as the average length of the root plus shoot in centimeters of seeds germinated by the ninth day.
12. Growth rate of root four-seven days, expressed as the average increase in length per day from the fourth to the seventh day of seeds germinated by the seventh day.
13. Growth rate of root seven-nine days, expressed as the average increase in length per day from the seventh to the ninth day of seeds germinated by the ninth day.
14. Growth rate of shoot four-seven days, expressed as the average increase in length per day from the fourth to the seventh day of seeds germinated by the seventh day.
15. Growth rate of shoot seven-nine days, expressed as the average increase in length per day from the seventh to the ninth day of seeds germinated by the ninth day.
16. Growth rate of total axis four-seven days, expressed as the average increase in length of root plus shoot per day from the fourth to the seventh day of seeds germinated by the seventh day.
17. Growth rate of total axis seven-nine days, expressed as the average increase in length of root plus shoot per day from the seventh to the ninth day of seeds germinated by the ninth day.

18. Root unit growth at four days, expressed as the average increase in length per day for the first four days in mm/mg seed weight of seeds germinated by the fourth day.

19. Root unit growth at seven days, expressed as the average increase in length per day for the first seven days in mm/mg seed weight of seeds germinated by the seventh day.

20. Root unit growth at nine days, expressed as the average increase in length per day for the nine days in mm/mg seed weight of seeds germinated by the ninth day.

21. Shoot unit growth at four days, expressed as the average increase in length per day for the first four days in mm/mg seed weight of seeds germinated by the fourth day.

22. Shoot unit growth at seven days, expressed as the average increase in length per day for the first seven days in mm/mg seed weight of seeds germinated by the seventh day.

23. Shoot unit growth at nine days, expressed as the average increase in length per day for the nine days in mm/mg seed weight of seeds germinated by the ninth day.

24. Total axis unit growth at four days, expressed as the average increase in length of root plus shoot per day for the first four days in mm/mg seed weight of seeds germinated by the fourth day.

25. Total axis unit growth at seven days, expressed as the

average increase in length of root plus shoot per day for the first seven days in mm/mg seed weight of seeds germinated by the seventh day.

26. Total axis unit growth at nine days, expressed as the average increase in length of root plus shoot per day for the nine days in mm/mg seed weight of seeds germinated by the ninth day.

Heterosis Study

Data collected on each plant in 1970 were:

1. Plant height - plant height was measured from ground level to the highest growing point on May 5.
2. Anthesis date - beginning on May 20 the nursery was checked every one or two days and anthesis recorded when a plant had at least two panicles with open flowers.
3. Panicles per plant - the number of panicles on each plant was counted two to four days before the plant was harvested for seed. An effort was made to exclude second growth panicles on which no anthesis had occurred.
4. Seed yield - the panicles of the 14 plants per row were cut using a hand sickle and threshed in a plot thresher. The seeds were cleaned with a hand screen and South Dakota blower and weighed to the nearest one-hundredth of a gram.

5. Fall vigor rating - fall vigor was rated from one to seven on the basis of overall plant size (width, height, density). The most vigorous plants were rated one. Ratings were made on November 24.

Forage and Seed Yield Phase

Data were collected for two forage harvests (April 3 and May 23, 1969). Seed harvest began on June 16 and was completed on June 21.

1. Forage phase - plants were harvested at a height of three inches using a self-propelled plot harvester. Forage was placed in burlap bags with a drawstring and dried in a forced-air oven at 175-180° F. Dried forage was weighed to the nearest gram on a Toledo scale.
2. Seed phase - the panicles of the 10 plants per row were cut using a hand sickle and threshed in a plot thresher. Seeds were cleaned with a Clipper cleaner and weighed to the nearest gram on a Toledo scale.

Seedling Vigor Selections

Four 100-seed samples from each of the six populations along with unselected Fortune, Alta, and Fawn were weighed to the nearest one-tenth mg and placed in petri dishes. The petri dishes were then put in a germinator with alternating temperature (16 hours at 59° F, eight hours at 77° F), and low light intensity. A vigor index for each entry was calculated with germinated seeds counted on the third, fourth, fifth, sixth, eighth, and tenth day after being placed in the germinator.

Fortune TX and S_1 Progeny

A vigor index test was conducted as in the seedling vigor selections except that four 35-seed samples were used for each top-cross and S_1.

Statistical Analysis

Seedling Vigor Phase

The functional analysis of variance was used to test for significance among groups, within groups, and among maturity groups within each type of progeny for each of the 34 variables measured. The general error term was used to test significance of the various groups. Simple correlation coefficients were computed between each of the 34 variables in all possible combinations for the S_1 and SX groups.

Heterosis Phase

The functional analysis of variance was used to test for significance among groups, within groups, and among maturity groups within each type of progeny for the five characteristics. Significance of the various groups was tested using the general error term. Simple correlation coefficients were computed between each of the five variables in all possible combinations for the parent, S_1, and SX groups. Simple correlation coefficients were also computed between each of the five characteristics and the 34 variables measured in the seedling vigor study.

Forage and Seed Yield Phase

The functional analysis of variance was used to test for significance among groups, within groups, and among entries within generations, with the general error term used to test for significance among the various progeny groups. Simple correlation coefficients were computed between forage and seed yield for the parents and five progeny groups.

Seedling Vigor Selections

A regular analysis of variance was used to test for significance among and within the three methods of selection.

Fortune TX and S_1 Progeny

A regular analysis of variance was used to test for significance between and within progeny groups for seed weight and vigor index. Simple correlation coefficients were computed between seed weight and vigor index within progeny groups and between TX and S_1 progenies for seed weight and vigor index.

RESULTS AND DISCUSSION

Heterosis Phase

The parents and S_1 and SX progeny were grown to determine if increased diversity of morphology, origin, and anthesis date result in heterosis for plant height, anthesis date, panicle number, seed yield, and fall vigor rating in tall fescue.

Means

Means for the parents and progeny groups (S_1, SX) for each characteristic are presented in Table 3, with mean squares and levels of significance shown in Table 4. Individual means, standard errors of the mean, and coefficients of variation are shown in Appendix Table 1.

Plant height. The three groups were quite similar in plant height with less than a centimeter separating parents and S_1 progeny while the SX progeny were four to five centimeters taller than the parents and S_1 progeny (Table 3). Great differences were present between maturity groups within parents and S_1 and SX progenies, however. Early parents and early S_1 progenies were more than twice as tall as late parents and late S_1 progenies, and early x early SX,s were over two and one-half times taller than late x late SX's, with the early x late SX's approximately halfway between. Significant

Table 3. Mean[1] plant height, anthesis date, panicle number, seed yield, and fall vigor rating for parents, S_1's, and SX's of tall fescue. Heterosis study. (Corvallis, Oregon. 1970)

Group	Plant height, May 5 (cm)	Anthesis, days after May 20	Panicle number	Seed yield (gm)	Fall vigor rating[2], Nov. 24
Early parents	73.24	7.52	30.20	15.31	3.02
Late parents	27.33	29.05	21.96	.52	5.01
All parents	52.83	17.09	26.54	8.74	3.91
Early S_1	68.21	8.97	25.75	7.34	3.37
Late S_1	29.10	30.24	23.22	.30	5.09
All S_1	53.54	16.94	24.80	4.70	4.01
Early x early SX	82.19	7.55	34.80	19.59	2.37
Late x late SX	29.15	29.40	25.99	.46	4.38
Early x late SX	61.58	13.95	36.43	4.95	2.68
All SX	57.64	16.97	32.41	8.33	3.14
Grand mean	56.81	16.43	28.80	8.73	3.56
Check (Fawn)	99.08	5.82	40.80	35.99	1.82

[1]Means are expressed on a per plant basis.

[2]Fall vigor rated 1-7, 1 equals the most vigorous.

Table 4. Mean squares and levels of significance for plant height, anthesis date, panicle number, seed yield, and fall vigor rating in tall fescue heterosis study. (Corvallis, Oregon. 1970)

Source of variation	d.f.	Plant height	Anthesis date	Panicle number	Seed yield	Fall vigor rating
Replications	3	67.382	2.710	78.650	16.851	.368*
Treatments	25	2645.474**	562.850**	367.898**	367.168**	4.923**
Among groups	3	2591.136**	159.246**	519.868**	1100.027**	8.533**
Within groups	22	2652.883**	617.887**	347.175**	267.233**	4.431**
Among parents	8	2985.515**	689.802**	330.396**	290.742**	5.198**
Among early	4	435.934*	48.275**	35.952	94.863**	.516**
Among late	3	1136.315**	401.555**	632.242**	1.224	1.433**
Among maturity groups	1	18731.437**	4120.651**	602.632**	1942.815**	35.223**
Among S_1	6	2610.791**	752.819**	185.162**	135.697**	4.364**
Among early	4	709.654**	61.891**	240.676**	133.913**	1.858**
Among late	1	191.59	409.982**	140.952*	.482	.025
Among maturity groups	1	12634.543**	3859.366**	6.034	278.103**	18.726**
Among SX	8	2351.447**	457.486**	485.777**	342.376**	3.714**
Among early x early	2	78.855	48.406**	119.482*	97.720**	.287
Among late x late	2	674.232*	263.229**	555.496**	.564	.599**
Among early x late	2	75.670	5.012	888.251**	70.326**	.019
Among maturity groups	2	8577.030**	1513.296**	379.878**	1200.893**	13.953**
Error	75	138.679	2.431	29.036	9.392	.108

*,** Significant at the five and one percent level respectively.

differences in height were also present among early and late parents, early S_1 progenies, and late x late SX progenies, with no differences among late S_1 progenies or early x early and early x late SX progenies.

Anthesis date. Parent and S_1 and SX progeny groups shared the same anthesis date (Table 3). Early parents and early S_1 progeny averaged 21.53 and 21.27 days earlier than the late parents and late S_1 progeny respectively, while the early x early SX progeny were 21.85 days earlier than the late x late SX progeny. Anthesis of early x late SX progeny occurred 6.40 days after that of early x early SX progeny but 15.45 days before anthesis of late x late SX progeny. There were significant differences for anthesis date within all parent and S_1 and SX progeny maturity groups with the exception of the early x late SX group.

Panicle number. The SX progeny averaged a non-significant 5.87 and 7.61 more panicles per plant than the parents and S_1 progeny respectively (Table 3). Early parents and early S_1 progeny had more panicles than late parents and late S_1 progeny. The early x late SX group had more panicles than the early x early group and had significantly more panicles than the late x late SX group with the early x early group exceeding the late x late group for panicle number. Significant differences in panicle number were observed within the late maturity group parents and within each S_1 and SX maturity group.

Seed yield. Seed production of parents and SX progeny was very similar (8.74 and 8.33 grams respectively), while the S_1 produced only 4.70 grams per plant (Table 3). These differences were not significant however. There were large differences in seed yield between maturity groups within parents, S_1 progeny and SX progeny because the later maturing groups set little seed. This was probably due to hot weather and lower availability of pollen later in the season. Differences within early parents and early S_1 progenies were significant as were differences within early x early and early x late SX progenies. Since late parents, late S_1 progenies and late x late SX progenies produced little seed, there were no differences within these maturity groups.

Fall vigor rating. Parents and S_1 progeny had similar fall vigor ratings with SX progeny significantly higher than both. The early x early SX group had a significantly higher fall vigor rating than all other maturity groups except the early x late SX group. Early parents and early S_1 progenies showed significantly more fall vigor than late parents and late S_1 progenies. Parents exhibited significant differences within maturity groups. This was also true of progenies within the early S_1 group and late x late SX group.

Associations Among Characteristics

There appeared to be definite relationships among anthesis date, plant height, seed yield, and fall vigor rating of parents and both progeny groups, so to better understand these phenomena, simple correlation coefficients among all five characteristics were computed. As presented in Table 5 anthesis date was significantly associated with plant height and fall vigor rating in parents, and S_1 and SX progenies. Anthesis date was also significantly associated with seed yield in the parent group. Panicle number was not significantly associated with any other characteristic, except fall vigor rating in the parent group. The reason that seed yield and panicle number were not associated is apparently because the later maturing parents, S_1 progenies, and SX progenies could not express their full genetic potential due to the effects of adverse environment on seedset.

Seed yield and fall vigor rating were significantly associated in parents and both progeny groups (-.738 - -.914), while plant height and fall vigor rating had the strongest association of all characteristics measured (r = -.939, -.944, and -.956 for parents, S_1 progeny and SX progeny respectively).

Heterosis

Means for each parent and S_1 and SX progeny for the five characteristics studied along with standard errors of the mean and coefficients of variation are presented in Appendix Table 1, with response to heterosis by SX progeny shown in Table 6. A summary of

Table 5. Simple correlation coefficients among five characteristics of parents and S_1 and SX progeny measured to study heterosis in tall fescue. (Corvallis, Oregon. 1970).

	Anthesis date	Panicle number	Seed yield	Plant height		Fall vigor rating	Anthesis date	Panicle number	Seed yield	Plant height
	Parents (n = 9)					S_1 (n = 8) (above diagonal); SX (n = 9) (below diagonal)				
Fall vigor rating	.917*	-.681*	-.878*	.939*	Fall vigor rating		.808*	-.361	-.914*	-.944*
Anthesis date		-.654	-.828*	-.980*	Anthesis date	.917*		-.143	-.553	-.913*
Panicle number			.497	.610	Panicle number	-.534	-.490		.426	.253
Seed yield				.877*	Seed yield	-.738*	-.662	.159		.784*
Plant height					Plant height	-.956*	-.967*	.469	.798*	

*Significant at the five percent level.
n = number of paried observations

Table 6. Expression of heterosis in SX progeny for five characteristics of tall fescue. (Corvallis, Oregon. 1970)

SX progeny as a percent of the:	Early x early SX			Late x late SX			Early x late SX		
	1x2	2x3	4x5	7x8	8x9	9x10	3x8	1x9	2x10
				Plant height					
Mid-parent	103.75	105.33	124.51	113.03	115.14	104.16	123.95	118.31	130.05
High-parent	97.48	103.60	118.38	84.42	107.91	78.59	81.87	74.26	74.64
				Anthesis date[1]					
Mid-parent	117.45	106.74	128.05	98.65	101.10	102.32	82.72	72.56	67.05
High-parent	125.60	123.37	129.94	124.46	113.79	115.31	213.99	318.18	320.84
				Panicle number					
Mid-parent	102.79	104.51	144.95	124.26	127.46	124.60	138.52	104.00	182.81
High-parent	95.67	94.77	139.25	121.74	73.13	75.57	133.91	59.58	159.02
				Seed yield					
Mid-parent	121.54	115.19	177.34	16.67	129.41	377.78	3.21	69.10	112.87
High-parent	89.71	107.35	158.11	12.90	70.97	309.09	1.76	34.71	56.74
				Fall vigor rating[1]					
Mid-parent	79.79	90.24	68.34	85.87	84.24	86.56	65.83	62.62	69.10
High-parent	80.94	93.71	79.27	91.44	92.01	92.34	85.34	96.40	96.15

[1] Smaller numerical values are desirable, therefore percentages less than 100.00 indicate heterosis.

response to heterosis by SX maturity groups is shown in Table 7.

Plant height. All SX progeny were taller than the mid-parent (MP), but none significantly so, and they ranged from 103.75 (cross 1x2) to 130.05 (cross 2x10) percent of the mid-parent (Table 6). Three single-cross progenies were taller than the high-parent with a range among all single-crosses of 74.26 to 118.38 percent of the high-parent. In relation to the mid-parent the early x late SX group exhibited the most heterosis (124.10 percent of the MP), while it was only 76.92 percent as tall as the high-parent (Table 7). The early x early group averaged 106.49 percent of the high-parent and all SX progeny combined averaged 115.36 and 91.24 percent of the mid-parent and high-parent respectively.

Anthesis date. Single-cross progeny varied from 28.05 (4x5) percent later to 32.95 (2x10) percent earlier than the mid-parent for anthesis date (Table 6). All early x late SX progenies were significantly earlier than the mid-parent, while all late x late progenies were very similar to the mid-parent. No SX progeny was as early as the early parent (HP), and the early x late group was much later than the early parent (Table 7). The extreme lateness of the early x late SX progenies in relation to the early parent is apparently due to the large difference in anthesis dates of the parents combined with a high narrow sense heritability of anthesis date ($b_{SX \cdot MP} = .951$).

These date show that anthesis date can be readily changed to

Table 7. Summary of response to heterosis for five characteristics by three SX progeny maturity groups and average heterosis for all SX progeny of tall fescue. (Corvallis, Oregon. 1970)

SX progeny as a percent of the:	Early x early SX's	Late x late SX's	Early x late SX's	Average of all SX progeny
		Plant height		
Mid-parent	111.20	110.78	124.10	115.36
High-parent	106.49	90.31	76.92	91.24
		Anthesis date[1]		
Mid-parent	117.41	100.69	74.11	97.40
High-parent	126.30	117.85	284.34	176.16
		Panicle number		
Mid-parent	117.42	125.44	141.78	128.21
High-parent	109.90	90.15	117.50	105.85
		Seed yield		
Mid-parent	138.02	174.62	61.73	124.79
High-parent	118.39	130.99	31.07	93.48
		Fall vigor rating[1]		
Mid-parent	79.46	85.56	65.85	76.96
High-parent	84.64	91.93	92.63	89.73

[1]Smaller numerical values are desirable, therefore percentages less than 100.00 indicate heterosis.

take advantage of a particular environment, or to facilitate natural crossing of otherwise diverse clones.

Panicle number. Heterosis for panicle number was highly variable with SX progeny ranging from 102.79 (1x2) to 182.8 (2x10) percent of the mid-parent (Table 6). Three single-cross progenies (4x5, 3x8, 2x10) had significantly more panicles than the high-parent. The early x late SX group exhibited the most heterosis producing 141.78 and 117.50 as many panicles as the mid-parent and high-parent respectively. The early x early SX group also exceeded the high-parent for panicle number. The average panicle number for all SX progenies was 128.21 and 105.85 percent of the mid-parent and high-parent respectively.

Seed yield potential may be increased greatly in certain single-crosses involving diverse clones. However, in the production of synthetic varieties, much of this increase would not be realized, and in the advent of hybrid tall fescue, breeders would not be concerned with the amount of seed produced by the hybrid.

Seed yield. All early x early SX progeny exceeded the mid-parent in seed production and two early x early crosses exceeded the high-parent (Table 7). Single-cross 4x5 produced significantly more seed than the high-parent (158.11 percent of HP). Due to the effects of environment on seed set of the late x late SX group, seed yields were too low and variable for accurate interpretation (Table 6). One early x late SX (3x8) also had very low seed yield, although it was no later than the other early x late SX's which had fair seed yields. However, seed set of SX 2x10 was probably affected somewhat also, because 82.81 percent more panicles than the MP resulted in only 12.87 percent greater seed production. Average seed yield of all SX progenies was 124.79 and 93.48 percent of the mid-parent and high-parent respectively.

These results emphasize the importance of using early maturing material in the breeding program if high seed yield is to be obtained.

Fall vigor rating. Fall vigor rating as taken in this study was a measure of overall vegetative vigor and progress made by plants from the time of establishment the previous fall.

There was a greater response to heterosis for fall vigor rating than for the other characteristics, resulting in all SX progenies rating higher than their respective high-parents. Single-cross 4x5 showed the greatest heterotic response in relation to the high-parent with a 20.73 percent higher fall vigor rating while all SX progenies averaged 10.27 percent above the high-parent (Table 7).

Heterosis above the mid-parent ranged from 9.76 percent in SX 2x3 to 37.38 percent in SX 1x9 with an average of 23.04 percent for all SX progenies. The early x late group exhibited the highest degree of heterosis as compared to the mid-parent averaging 34.15 percent higher, while the early x early group had the highest rating in comparison to the high-parent averaging 15.36 percent above the HP.

Performance of the early x early group (especially SX 4x5) indicated that diversity of anthesis date was not required to obtain heterosis for vegetative vigor. Results also showed that only one parent with high vegetative vigor was necessary to obtain high vegetative vigor in single-cross progeny.

Summary of Heterosis Phase

Heterosis (average of all SX's) above the mid-parent was demonstrated for plant height (15.36 percent), early anthesis date (2.60 percent), panicle number (28.21 percent), seed yield (24.79 percent), and fall vigor rating (23.04 percent). Heterosis above the high-parent was expressed for panicle number (5.85 percent) and fall vigor rating (10.27 percent). The early x late SX group in most cases produced progenies with greater response to heterosis than either the early x early or late x late groups, and had the greatest heterosis as compared to the mid-parent for four of the five characteristics measured.

Two SX progenies were particularly outstanding. Progeny of SX 2x10 showed considerable heterosis above the mid-parent for plant height, early anthesis date, panicle number and fall vigor rating. This SX also had significantly more panicles than the high-parent.

Despite having one parent with a low fall vigor rating (5.09), single-cross 2x10 also showed heterosis above the high-parent (HP = 2.86) for this characteristics. Single-cross 4x5 exceeded the high-parent by 18.38, 39.25, 58.11, and 31.66 percent for plant height, panicle number, seed yield, and fall vigor rating respectively. Single-cross 4x5 also produced slightly more panicles than the check variety Fawn, and was not significantly different from Fawn in fall vigor rating.

Results showed that for the parents studied, diversity of anthesis date increased the number of single-cross progenies expressing heterosis, but that diverse anthesis date in addition to the diversity present for morphology and origin was not a prerequisite for obtaining heterosis in tall fescue. It is particularly significant that crosses to parents with very low vegetative vigor always resulted in progeny with more vegetative vigor than the high-parent.

Amounts of heterosis observed for certain characteristics in this study were larger and more frequent than have been observed previously in tall fescue studies of Echeverri (1964), Matheson (1965), and Thomas (1967). It appears that greater diversity among parents may be responsible for the heterosis observed. Due to the growth chamber space and logistics required when crossing genotypes of diverse anthesis date, only nine single-crosses were studied. Whether or not the results obtained from these single-crosses is indicative of diverse crosses in general remains to be tested.

Seed and Seedling Vigor Phase

Single-cross, first generation selfed, topcross, and open-pollinated seed and seedlings were studied to: 1) test for differences among experimental populations and compare methods of measuring seed and seedling vigor in tall fescue, 2) determine the relationship among seed and seedling vigor characteristics and between seed and seedling vigor and five other agronomic characteristics of tall fescue, 3) evaluate one cycle of selection for high and low seedling vigor using three methods of selection, and 4) study the breeding behavior of seedling vigor.

Means

Individual and group means for S_1's and SX's, standard errors of the mean, and coefficients of variation for each variable are presented in Tables 8-13, with mean squares and levels of significance shown in Appendix Tables 2-7.

Seed weight and germination. There was tremendous variation in seed weight (36.3-98.9 mg) resulting in significant differences among and within all groups (Table 8; Appendix Table 2). Single-cross seed was heavier than S_1 seed but the difference was not significant. S_1 1 had the heaviest seed of any entry including the check variety Fawn.

Table 8. Means, standard errors of the mean ($s\bar{x}$) and coefficients of variation (C.V.) for five seed vigor characteristics of tall fescue. (Corvallis, Oregon. 1970)

Identification	Percent germination	Seed weight mg/40 seeds	Oxygen uptake	Oxygen uptake adjusted for germination	Oxygen uptake adjusted for germination and weight
		Early S_1's			
1	94	98.9	16.48	17.59	16.95
2	87	52.1	8.30	9.53	17.47
3	93	78.5	13.73	14.96	18.21
4	98	75.2	13.33	13.52	17.15
5	100	75.4	14.38	14.38	18.18
Average	94	76.0	13.24	14.00	17.59
		Late S_1's			
7[a]	70	36.3	10.15	14.50	38.14
8	85	60.9	9.30	10.96	17.21
10	92	55.1	12.90	14.02	24.31
Average	82	50.8	10.78	13.16	26.55
All S_1 average	90	66.6	12.32	13.68	20.95
		Early x early SX			
1x2	98	86.8	13.55	13.78	15.18
2x3	93	62.3	11.08	12.00	18.62
4x5	94	80.0	13.55	14.45	17.31
Average	95	76.4	12.73	13.41	17.04
		Late x late SX			
7x8	97	72.7	7.35	7.59	9.97
8x9	52	73.5	7.28	14.66	18.95
9x10	96	63.4	7.40	7.71	11.61
Average	82	69.9	7.34	9.99	13.51
		Early x late SX			
3x8	94	71.9	9.25	9.84	13.05
1x9	87	86.3	6.85	8.03	8.84
2x10	97	62.6	9.90	10.19	15.54
Average	93	73.6	8.67	9.35	12.48
All SX average	90	73.3	9.58	10.92	14.34
Fawn	97	95.5	21.78	22.46	22.46
Grand mean	91	73.59	11.55	12.69	16.53
$s\bar{x}$	3.33	2.90	1.74	2.20	2.90
C.V.	5.11	5.59	21.30	24.48	24.81

[a]Not duplicated, therefore not included in analysis or grand mean.

Most seed lots had high germination, but seed of S_1 7 and SX 8x9 did germinate poorly. Seed of S_1 7 was very small and some were shrunken but seed of SX 8x9 was of average size and normal appearance.

Respiration measurements. There were fewer significant differences among and within groups for respiration than for other measures of seedling vigor (Appendix Tables 2 and 3). The only differences in oxygen uptake and carbon dioxide evolution were among SX maturity groups and within early S_1's, with no significant difference between S_1 and SX groups. There did seem to be a trend in oxygen uptake and carbon dioxide evolution in that both were highest in early S_1's and early x early SX's, low in late S_1's and late x late SX's, and intermediate in early x late SX's (Tables 8 and 9).

Due to the lack of differences in oxygen uptake, carbon dioxide evolution, and respiration quotient (RQ), these characteristics would be of little use in screening for higher seedling vigor.

Vigor index. Statistical differences were exhibited among and within all groups for vigor index (Appendix Table 3). The S_1's averaged higher than SX's and one S_1 (S_1 5) was above the check variety Fawn. As with measures of respiration, early S_1 and early x early SX seed were highest in vigor index, with late S_1's and late x late SX's low, and early x late SX's intermediate. Single-cross 8x9 had an unusually low vigor index (1.58) as compared to the average

Table 9. Means, standard errors of the mean ($s\bar{x}$), and coefficients of variation (C. V.) for five seed vigor characteristics of tall fescue. (Corvallis, Oregon. 1970)

Identification	CO_2 evolution	CO_2 evolution adjusted for germination	CO_2 evolution adjusted for germination and weight	RQ	Vigor index
		Early S_1's			
1	13.75	14.68	14.15	.835	4.97
2	6.40	7.34	13.47	.767	4.31
3	11.60	12.67	15.43	.838	5.14
4	10.25	10.40	13.19	.771	5.18
5	11.65	11.65	14.75	.830	6.01
Average	10.73	11.35	14.20	.808	5.12
		Late S_1's			
7[a]	7.90	11.29	29.70	.778	3.33
8	7.35	8.65	13.55	.807	3.70
10	10.15	11.04	19.16	.787	4.98
Average	8.47	10.33	20.80	.791	4.00
All S_1 average	9.88	10.96	16.68	.802	4.70
		Early x early SX			
1x2	11.95	12.17	13.40	.892	5.58
2x3	8.85	9.57	14.80	.810	4.39
4x5	11.35	12.11	14.52	.835	5.00
Average	10.72	11.28	14.24	.846	4.99
		Late x late SX			
7x8	7.00	7.22	9.47	.981	4.67
8x9	5.70	11.56	14.94	.778	1.58
9x10	5.05	5.27	7.92	.681	4.38
Average	5.92	8.02	10.78	.813	3.54
		Early x late SX			
3x8	7.75	8.24	10.93	.839	4.87
1x9	4.50	5.25	5.79	.664	3.75
2x10	7.05	7.22	10.95	.703	5.28
Average	6.43	6.90	9.22	.735	4.63
All SX average	7.69	8.73	11.30	.798	4.39
Fawn	16.80	17.33	17.33	.773	5.63
Grand mean	9.244	10.139	13.162	.799	4.672
$s\bar{x}$	1.35	1.76	2.33	.077	.278
C.V.	20.59	24.58	25.02	13.77	8.43

[a]Not duplicated, therefore not included in analysis or grand mean.

(4.67), even though oxygen uptake was about the same as other late x late SX's.

Vigor index had a lower coefficient of variation than other characteristics and also required less time and space to measure, thus it has an advantage over characteristics which may be equally effective in determining seedling vigor.

Length of root, shoot and axis. There were statistical differences among and within most groups for length of root, shoot, and total axis at four, seven, and nine days (Appendix Tables 4 and 5). Seed from earlier maturing S_1 and SX groups in most cases had significantly longer roots and shoots on each measuring date than later maturing S_1 and SX groups (Tables 10 and 11). Average root and shoot length of all S_1's and SX's were very similar for the three periods. Single-cross seed of 8x9 had no root or shoot growth at four days and had little growth by the ninth day.

Root growth commenced before shoot growth in all S_1's and SX's and roots were still longer on the seventh day, with shoot length surpassing root length by the ninth day in most cases. The check (Fawn) known to have high seedling vigor had the longest roots and among the shortest shoots on the fourth day, resulting in a much higher root to shoot ratio than S_1's and SX's. By the ninth day, shoots of Fawn had surpassed those of all S_1's and SX's in length.

Root length may be a better indication of early seedling vigor

Table 10. Means, standard errors of the mean ($s\bar{x}$), and coefficients of variation (C. V.) for six seedling vigor characteristics of tall fescue. (Corvallis, Oregon. 1970)

Identification	Root length (cm)			Shoot length (cm)		
	4 days	7 days	9 days	4 days	7 days	9 days
			Early S_1's			
1	.94	2.82	4.31	.20	1.56	3.57
2	.54	1.71	2.51	.42	1.65	3.23
3	.70	2.44	3.44	.20	1.65	3.55
4	.98	2.81	4.35	.32	1.45	3.30
5	1.15	3.19	4.45	.50	2.60	4.77
Average	.86	2.59	3.81	.33	1.78	3.68
			Late S_1's			
7[a]	.54	.95	1.18	.27	.88	1.70
8	.57	1.56	2.14	.23	1.23	2.69
10	.62	1.60	2.09	.25	1.39	2.99
Average	.58	1.37	1.80	.25	1.17	2.46
All S_1 average	.76	2.14	3.06	.30	1.55	3.23
			Early x early SX			
1x2	1.22	3.44	4.81	.37	2.50	4.61
2x3	.93	2.29	3.26	.26	1.49	3.72
4x5	1.61	3.44	4.64	.55	2.23	4.33
Average	1.25	3.06	4.24	.39	2.07	4.22
			Late x late SX			
7x8	.75	2.40	3.68	.13	1.47	3.97
8x9	0	.98	1.40	0	.30	.84
9x10	.50	2.08	2.82	.11	1.25	2.52
Average	.42	1.82	2.63	.08	1.01	2.44
			Early x late SX			
3x8	.87	2.33	3.49	.27	1.98	4.34
1x9	.48	1.97	3.40	.10	.73	2.00
2x10	.95	2.60	3.44	.43	2.49	4.70
Average	.77	2.30	3.44	.27	1.73	3.68
All SX average	.81	2.39	3.44	.25	1.60	3.45
Fawn	1.64	4.29	6.03	.21	2.48	5.12
Grand mean	.850	2.468	3.545	.268	1.674	3.544
$s\bar{x}$	.084	.207	.292	.059	.242	.251
C.V.	14.00	11.87	11.65	31.23	20.47	10.01

[a]Not duplicated, therefore not included in analysis or grand mean.

Table 11. Means, standard errors of the mean ($s\bar{x}$), and coefficients of variation (C. V.) for six seedling vigor characteristics of tall fescue. (Corvallis, Oregon. 1970)

Identification	Length of total axis (cm) 4 days	7 days	9 days	Root growth rate/day (cm) 4th-7th day	7th-9th day	Shoot growth rate/day (cm) 4th-7th day
			Early S_1's			
1	1.14	4.38	7.88	.71	.84	.48
2	.96	3.36	5.74	.46	.47	.48
3	.89	3.87	6.99	.64	.53	.50
4	1.30	4.27	7.66	.70	.90	.40
5	1.64	5.79	9.22	.71	.65	.71
Average	1.19	4.33	7.50	.64	.68	.51
			Late S_1's			
7[a]	.81	1.83	2.88	.23	.15	.25
8	.79	2.79	4.84	.44	.45	.38
10	.86	2.99	5.08	.37	.32	.40
Average	.82	2.54	4.27	.35	.31	.34
All S_1 average	1.05	3.66	6.29	.53	.54	.45
			Early x early SX			
1x2	1.59	5.94	9.42	.82	.70	.73
2x3	1.20	3.78	6.98	.60	.60	.45
4x5	2.16	5.67	8.97	.76	.73	.62
Average	1.65	5.13	8.46	.73	.68	.60
			Late x late SX			
7x8	.87	3.87	7.65	.67	.71	.47
8x9	0	1.29	2.23	.33	.56	.10
9x10	.61	3.33	5.34	.61	.57	.41
Average	.49	2.83	5.07	.53	.61	.33
			Early x late SX			
3x8	1.14	4.30	7.83	.62	.62	.60
1x9	.58	2.70	5.40	.59	.92	.23
2x10	1.38	4.82	8.14	.63	.46	.73
Average	1.03	3.94	7.12	.61	.67	.52
All SX average	1.06	3.97	6.88	.62	.65	.48
Fawn	1.84	6.80	11.15	.97	.95	.76
Grand mean	1.115	4.115	7.089	.625	.646	.497
$s\bar{x}$	.124	.402	.491	.049	.073	.072
C. V.	15.75	13.83	9.80	11.17	15.91	20.48

[a]Not duplicated, therefore not included in analysis or grand mean.

than shoot length, and may be as accurate as total axis length, which requires twice as much time to measure.

Growth rate. Significant differences in root growth rate from the fourth to seventh day were observed among and within all groups except the late S_1's and early x late SX's (Appendix Tables 5 and 6). There were significant differences among and within SX groups for rate of shoot growth from the fourth to seventh day, but there were no differences for S_1's.

Differences in growth rate of roots, shoots, and axes were not as pronounced in the second growth period as in the first. Single-crosses averaged slightly higher than S_1's in root and shoot growth rate (Tables 11 and 12). Early S_1 and early x early SX seedlings grew at a faster rate than late S_1 and late x late SX seedlings. Early x late SX seedlings were about halfway between early x early and late x late seedlings in growth rate. Roots grew at nearly the same rate from the fourth to seventh day and seventh to ninth day, but shoots grew faster during the latter period.

Unit growth. When unit growth was calculated in order to separate growth from the effects of seed weight, significant differences were recorded in most instances (Appendix Tables 6 and 7). There were no differences however, among late S_1's for root or shoot unit growth during any growth period, or among early x early SX's for most growth periods. The early x early SX group had higher root,

Table 12. Means, standard errors of the mean ($s\bar{X}$), and coefficients of variation (C.V.) for six seedling vigor characteristics of tall fescue. (Corvallis, Oregon. 1970)

Identification	Shoot growth rate/day (cm) 7th-9th day	Total axis growth rate/day (cm) 4th-7th day	Total axis growth rate/day (cm) 7th-9th day	Root unit growth 4 days	Root unit growth 7 days	Root unit growth 9 days
			Early S_1's			
1	1.05	1.19	1.89	.95	1.63	1.94
2	.86	.94	1.32	1.04	1.88	2.15
3	.93	1.13	1.46	.89	1.78	1.95
4	.99	1.10	1.88	1.30	2.13	2.57
5	1.11	1.42	1.75	1.52	2.41	2.61
Average	.99	1.16	1.66	1.14	1.97	2.24
			Late S_1's			
7[a]	.42	.48	.57	1.48	1.49	1.44
8	.85	.81	1.30	.94	1.47	1.57
10	.87	.77	1.18	1.12	1.66	1.68
Average	.71	.69	1.02	1.18	1.54	1.56
All S_1 average	.88	.98	1.42	1.16	1.81	1.99
			Early x early SX			
1x2	1.04	1.55	1.74	1.41	2.26	2.46
2x3	1.16	1.06	1.76	1.49	2.10	2.32
4x5	1.13	1.37	1.85	2.02	2.46	2.58
Average	1.11	1.33	1.79	1.64	2.27	2.45
			Late x late SX			
7x8	1.28	1.14	1.99	1.03	1.88	2.25
8x9	.37	.43	.93	0	.79	.85
9x10	.75	1.02	1.31	.79	1.87	1.97
Average	.80	.86	1.41	.61	1.51	1.69
			Early x late SX			
3x8	1.19	1.22	1.81	1.21	1.85	2.16
1x9	.74	.83	1.65	.56	1.30	1.75
2x10	1.16	1.35	1.62	1.20	2.36	2.43
Average	1.03	1.13	1.69	.99	1.84	2.11
All SX average	.98	1.11	1.63	1.08	1.87	2.08
Fawn	1.38	1.73	2.32	1.41	2.56	2.80
Grand mean	.992	1.121	1.633	1.111	1.905	2.120
$s\bar{X}$	.087	.097	.144	.118	.174	.164
C.V.	12.37	12.20	12.50	15.00	12.88	10.92

[a]Not duplicated, therefore not included in analysis or grand mean.

shoot, and total axis unit growth than the late x late SX group, and again the early x late SX group was about halfway between early x early and late x late SX groups (Tables 12 and 13).

The early S_1 group made more root and shoot growth per unit weight than late S_1's at seven and nine days but not at four days. The S_1 group as a whole had a slightly higher unit growth than the SX group for six of the nine unit growth measurements.

Unit growth was not an accurate measure of seedling vigor because several entries with light seed were favored, and the check variety (Fawn) with high seedling vigor and seed weight rated low.

Associations Among Characteristics

All possible combinations of simple correlation coefficients were computed among seedling vigor characteristics, with values among 12 characteristics for S_1's and SX's presented in Table 14.

Seed weight of the S_1 group was significantly associated with oxygen uptake (r = .823), root length at seven and nine days (r = .865 and .882 respectively), and several other characteristics. Seed weight was not associated with shoot growth rate or unit growth in the S_1 group. In the SX group seed weight had a low association with all characteristics.

Vigor index of S_1 seed was significantly associated with all other characteristics except seed weight and shoot unit growth. In the SX

Table 13. Means, standard errors of the mean ($s\bar{X}$), and coefficients of variation (C.V.) for six seedling vigor characteristics of tall fescue. (Corvallis, Oregon. 1970)

Identification	Shoot unit growth for:			Total axis unit growth for:		
	4 days	7 days	9 days	4 days	7 days	9 days
			Early S_1's			
1	.20	.90	1.61	1.15	2.53	3.55
2	.81	1.82	2.76	1.85	3.69	4.91
3	.26	1.20	2.01	1.14	2.82	3.96
4	.43	1.10	1.36	1.73	3.24	4.53
5	.66	1.96	2.80	2.17	4.38	5.42
Average	.47	1.40	2.11	1.61	3.33	4.47
			Late S_1's			
7[a]	.75	1.38	2.08	2.23	2.87	3.52
8	.38	1.16	1.97	1.30	2.63	3.54
10	.46	1.44	2.41	1.56	3.09	4.09
Average	.53	1.33	2.15	1.70	2.86	3.72
All S_1 average	.49	1.37	2.13	1.64	3.16	4.19
			Early x early SX			
1x2	.43	1.65	2.36	1.83	3.91	4.82
2x3	.42	1.37	2.65	1.92	3.46	4.97
4x5	.69	1.60	2.41	2.70	4.05	4.99
Average	.51	1.54	2.47	2.15	3.81	4.93
			Late x late SX			
7x8	.18	1.15	2.42	1.20	3.04	4.67
8x9	0	.23	.51	0	1.00	1.35
9x10	.18	1.13	1.76	.96	2.99	3.73
Average	.12	.84	1.56	.72	2.34	3.25
			Early x late SX			
3x8	.38	1.57	2.68	1.58	3.41	4.83
1x9	.12	.48	1.03	.67	1.79	2.78
2x10	.69	2.26	3.32	2.20	4.39	5.76
Average	.40	1.44	2.34	1.48	3.20	4.46
All SX average	.34	1.27	2.12	1.45	3.12	4.21
Fawn	.22	1.48	2.38	1.92	4.06	5.18
Grand mean	.383	1.324	2.144	1.522	3.205	4.299
$s\bar{X}$	.083	.217	.165	.175	.346	.294
C.V.	30.47	23.16	10.89	16.28	15.26	9.66

[a]Not duplicated, therefore not included in analysis or grand mean.

Table 14. Simple correlation coefficients* among 12 vigor characteristics in S_1 (upper diagonal) and SX (lower diagonal) seed and seedlings of tall fescue. (Corvallis, Oregon. 1970)

	40-Seed weight	Oxygen uptake	Vigor index	Root length 7 days	Root length 9 days	Shoot length 9 days	Axis length 9 days	Growth rate of root 4th-7th day	Growth rate of shoot 4th-7th day	Growth rate of axis 4th-7th day	Root unit growth 7 days	Shoot unit growth 7 days
40-Seed weight		.823	.670	.865	.882	.688	.836	.912	.560	.821	.322	-.422
Oxygen uptake	.235		.740	.768	.752	.583	.710	.713	.455	.654	.333	-.338
Vigor index	.011	.592		.883	.837	.915	.905	.804	.826	.878	.799	.218
Root length, 7 days	.304	.833	.883		.991	.889	.988	.977	.781	.965	.749	-.267
Root length, 9 days	.439	.733	.871	.967		.840	.973	.985	.716	.941	.714	-.101
Shoot length, 9 days	.063	.677	.929	.850	.810		.943	.837	.971	.962	.801	.343
Axis length, 9 days	.158	.736	.950	.945	.935	.965		.963	.854	.989	.780	.083
Growth rate of root, 4th-7th day	.325	.687	.919	.963	.976	.817	.929		.716	.949	.654	-.150
Growth rate of shoot, 4th-7th day	-.050	.715	.926	.864	.784	.961	.930	.814		.901	.767	.498
Growth rate of axis, 4th-7th day	.103	.737	.969	.945	.902	.948	.975	.931	.970		.760	.136
Root unit growth, 7 days	-.151	.741	.920	.893	.805	.914	.911	.847	.918	.932		.540
Shoot unit growth, 7 days	-.291	.631	.865	.741	.632	.924	.840	.670	.959	.884	.912	

*Correlations of .707 and .666 are significant at the five percent level for S_1 and SX groups respectively.

group vigor index was highly associated with other characteristics with the exception of seed weight and oxygen uptake.

Root, shoot, and axis length of SX's were strongly associated with each other and with all other characteristics except seed weight, the only exception being that root length at nine days was not significantly associated with shoot unit growth. In the S_1 group root length and axis length were strongly associated with other characteristics except shoot unit growth, while shoot length was significantly associated with all characteristics except seed weight, oxygen uptake and shoot unit growth.

Root, shoot, and axis growth rates were highly associated with most other characteristics with the most notable exceptions being that growth rates were neither associated with shoot unit growth in the S_1 group nor seed weight in the SX group.

In the S_1 group root unit growth was significantly associated with most other seedling characteristics but shoot unit growth was not associated with any other characteristic. In the SX group root unit growth was significantly associated with all seedling characteristics, while shoot unit growth was associated with all except root length at nine days.

Associations Between Seed and Seedling and Mature Plant Characteristics

The weight of 40 seeds was significantly associated with plant height, seed yield and fall vigor rating in S_1's but seed weight was not associated with any characteristic in SX's (Table 15). Oxygen uptake had a strong relationship with seed yield and fall vigor rating in S_1 and SX populations and was also significantly associated with plant height of SX's.

Root length at seven and nine days was correlated with plant height, seed yield and fall vigor rating in S_1's and SX's, while shoot length, shoot growth rate, and shoot unit growth were correlated with panicle number in SX's. Growth rate of the root was associated with plant height, seed yield and fall vigor rating in the S_1 population but not in the SX population. Unit growth of the root and vigor index were not strongly associated with any plant characteristic.

It appears that selection on the basis of several of the seed and seedling vigor characteristics would result in improvement in mature plant characteristics.

Breeding Behavior of Seedling Vigor

Mean weight and vigor index of topcross (TX) and S_1 seed are presented in Table 16 with mean squares and levels of significance shown in Table 17.

Thirty-five seed weight ranged from 40.68 to 64.95 mg with a range in vigor index of from 5.82 to 8.06 (Table 16). There were significant differences between and within TX's and S_1's in both seed

Table 15. Simple correlation coefficients* between 12 seed and seedling vigor characteristics and five mature plant characteristics in S_1 and SX populations of tall fescue. (Corvallis, Oregon. 1970)

	S_1					SX				
	Plant height	Anthesis date	Panicle number	Seed yield	Fall vigor rating	Plant height	Anthesis date	Panicle number	Seed yield	Fall vigor rating
40-Seed weight	.725	-.513	.568	.862	-.862	.397	-.349	-.142	.461	-.407
Oxygen uptake	.602	-.241	.447	.814	-.724	.777	-.655	.455	.891	-.733
Vigor index	.456	-.245	.217	.600	-.600	.551	-.510	.540	.432	-.605
Root length, 7 days	.706	-.533	.493	.825	-.834	.692	-.580	.493	.753	-.711
Root length, 9 days	.733	-.579	.550	.844	-.868	.740	-.651	.454	.714	-.755
Shoot length, 9 days	.520	-.394	.116	.635	-.644	.621	-.603	.791	.430	-.655
Axis length, 9 days	.671	-.524	.386	.789	-.808	.705	-.655	.680	.578	-.732
Growth rate of root, 4th-7th day	.740	-.611	.558	.801	-.858	.620	-.530	.379	.638	-.629
Growth rate of shoot, 4th-7th day	.485	-.394	-.074	.546	-.560	.542	-.506	.697	.453	-.611
Growth rate of axis, 4th-7th day	.683	-.560	.312	.752	-.793	.607	-.548	.595	.551	-.652
Root unit growth, 7 days	.377	-.354	.131	.407	-.451	.554	-.466	.582	.570	-.578
Shoot unit growth, 7 days	-.165	.040	-.700	-.233	.208	.459	-.437	.721	.350	-.542

*Correlations of .707 and .666 are significant at the five percent level for S_1 and SX groups respectively.

Table 16. Means, standard errors of the mean ($s\bar{x}$), and coefficients of variation (C. V.) for weight and vigor index of topcross and S_1 seed of tall fescue. (Corvallis, Oregon. 1970)

Clone	Topcross		S_1	
	Seed weight	Vigor index	Seed weight	Vigor index
1	48.80	7.80	42.70	7.67
2	50.53	8.06	45.90a	7.51
3	63.60	7.82	58.68	7.56
4	52.50	6.56	55.95	6.65
5	47.60	6.99	42.33	7.62
6	51.38	6.79	47.03	6.80
7	54.58	6.47	47.00	6.40
8	64.45	7.82	66.75a	7.19
9	54.83	7.24	45.03	7.30
10	59.05	7.52	53.30	7.29
11	57.93	7.80	59.05	7.88
12	50.60	7.34	43.28	7.02
13	50.73	7.84	--- b	--
14	51.15	7.28	46.03	7.45
15	44.40c	5.82	--- b	--
16	55.20	7.16	41.98	7.23
17	42.28	7.74	39.08	7.21
18	51.98	7.45	52.03	7.16
19	50.58	7.60	47.98	7.43
20	56.58	7.61	52.93	7.43
21	51.73	7.92	43.70c	6.40
22	64.95	7.69	44.43	6.47
23	56.78	7.66	51.10	6.89
24	40.68	5.79	35.33	6.73
25	50.78	7.73	45.20	6.77
Average	52.94	7.34	48.12	7.13
Fawn	101.68	10.02		
$s\bar{x}$	1.64	.20		
C. V.	6.53	5.42		

[a] Two samples
[b] Insufficient seed for testing
[c] Three samples

weight and vigor index (Table 17).

Table 17. Mean squares and levels of significance for weight and vigor index of topcross and S_1 seed of tall fescue. (Corvallis, Oregon. 1970)

Source of variation	d. f.	Mean squares and significance	
		Seed weight	Seed vigor index
Treatment	43	182.880**	1.009**
Among groups	1	1462.444**	2.845**
Within groups	42	152.414**	.966**
Among topcross	23	144.915**	1.187**
Among S_1	19	161.493**	.698**
Error	132	10.695	.156

**Significant at the one percent level.

There was a significant association between TX's and S_1's for seed weight (r = .668, n = 20). Vigor index of TX's and S_1's was also significantly correlated (r = .495, n = 20). As in SX and S_1 groups discussed in the preceding section there was a poor association of seed weight and vigor index in TX and S_1 groups (r = .394 and .256 respectively).

The association of TX and S_1 performance for vigor index and seed weight suggests that neither characteristic responds to heterosis. If either heterosis or inbreeding depression had occurred with regularity (and theoretically both should occur together), there would have been a low association between TX and S_1 performance. This was not the case however, and if the top five clones were selected on the basis of topcross performance, four would also be included among the top five S_1's for seed weight and vigor index respectively (excluding clone 13 which had insufficient S_1 seed).

Single-cross and S_1 data from the preceding section (Tables 8-13) also tend to indicate a lack of heterosis. For seed weight and for all seedling vigor measurements the early S_1 group and early x early SX group were high and the late S_1 group and late x late SX group low, with crosses between early and late resulting in progeny with intermediate seed weight and seedling vigor. There was no inbreeding depression in these S_1's as the S_1 and SX groups had the same seed weight and the S_1's had a higher vigor index than SX's.

Seedling Vigor Selections

The turf-type tall fescue variety Fortune which has poor seedling vigor was used as a source of material for comparing methods of selection for high and low seedling vigor. This variety was developed specifically for use as roadside turf and has several highly desirable attributes for this purpose, such as short stature, narrow leaves, and dark green color. Faster seedling emergence and early growth rate would greatly enhance the usefulness of this variety. In attempting to improve seedling vigor of Fortune, three methods of selection were employed. Method A, seedling performance of seeds from individual panicles, is based on selection for seedling vigor per se, method B, seed weight, is based on selection for a correlated character, while method C, emergence from deep planting, is based on selection for a possible component of seedling vigor.

The mean seed weight and seed vigor index of the unselected population (syn-2 seed) and each of the selected populations is shown in Table 18. Each of the populations selected for high seedling vigor produced heavier seed with greater vigor than that from the unselected population. Seeds produced from high selections based on emergence from deep planting, seed weight, and head performance were 10.26, 14.61, and 11.98 percent heavier than seed from the unselected population respectively, while the same seeds were 14.70, 14.86, and 14.96 percent higher in seed vigor index respectively.

Considering selection in a positive direction all three methods of selection appeared to be effective for increasing seed weight and vigor. However, when selection for decreased vigor was considered, each of these three populations also produced seeds that were significantly heavier and seedlings that were more vigorous than the unselected population. There were no significant differences among or within methods of selection for seed vigor index, although within each method selection for increased vigor resulted in seedlings with slightly more vigor (2.50-3.60 percent) than those from selection in the negative direction (Tables 18 and 19). Significant differences in

Table 18. Means, standard errors of the mean ($s\bar{x}$), and coefficients of variation (C. V.) for seed weight and vigor index of Fortune tall fescue and six populations selected from it for high and low seedling vigor. (Corvallis, Oregon. 1970)

Method of selection	100-Seed weight (mg)	Percent above unselected	Seed vigor index	Percent above unselected
Unselected (Fortune)	151.03		18.78	
Emergence from deep planting				
Vigorous	166.53	10.26	21.54	14.70
Non-vigorous	163.33	8.14	20.85	11.10
Average	164.93		21.20	
Seed weight				
Heavy	173.10	14.61	21.57	14.86
Light	162.93	7.88	21.07	12.19
Average	168.02		21.32	
Head performance				
Good	169.13	11.98	21.59	14.96
Poor	165.10	9.32	21.12	12.46
Average	167.12		21.36	
Fawn	294.53		25.46	
Grand mean	164.44		20.93	
$s\bar{x}$	2.97		.26	
C. V.	3.61		2.45	

seed weight among selected populations were observed however. The population selected on the basis of high seed weight produced heavier seeds than populations selected from light seeds and from non-vigorous seedlings. As was the rule with seed vigor index, the high selection exceeded the low selection for seed weight (2.66-6.73 percent) within each method of selection.

Table 19. Mean squares and levels of significance for seed weight and seed vigor index of Fortune tall fescue and six populations selected from it for high and low seedling vigor. (Corvallis, Oregon. 1970)

Source of variation	d. f.	Mean squares and significance	
		Seed weight	Seed vigor index
Treatment	6	189.95**	3.972**
Among group	3	293.48**	7.228**
Within group	3	86.41	.717
Error	21	35.24	.262

**Significant at the one percent probability level.

Each of the selected populations was enclosed in a muslin cage prior to anthesis to ensure isolation, with air circulated within each cage twice daily. Due to lack of pollen at the proper time, higher temperatures (av. 6^{o} F warmer inside the cage), decreased light intensity, or a combination of the three, seed set was noticeably lower than on the unselected population which was isolated by its location. The reduced seed set of the caged populations is probably the primary reason for their heavier seed weight and higher seed vigor index. Since fewer seeds were being filled per spikelet and per panicle, more photosynthate was available per seed. A screen size distribution test showed that all caged populations produced more seeds of the larger sizes than the unselected population.

Schaaf and Rogler (1963) emphasized the importance of considering seed set when selecting for higher seed weight in crested wheatgrass. Their study illustrated that seed weight can be influenced by seed set and the present study appears to bear this out. It is fortunate that selection in the negative direction was included in this study otherwise erroneous conclusions concerning the effectiveness of selection might have been drawn. Instead of a 14 to 15 percent gain in seedling vigor over the unselected population we had a maximum of 3.6 percent gain over the selection in a negative direction, therefore it is doubtful that progress was made.

The three methods of selection used in this study were chosen because they were relatively quick and simple. But since a seed's size is likely influenced by its location on the spikelet and on the panicle, progress made by selecting heavy or vigorous seeds from a bulk sample may be slight, while more progress would be expected from selection based on head performance. There did not appear to be any advantage for one method over the others in this study.

The best Fortune clones discussed in the preceding section produced topcross and S_1 seed little more than 50 and 75 percent as heavy and vigorous respectively as the variety Fawn. The pollen parent appeared to have little effect on weight and vigor of topcross and S_1 seed. Therefore, to improve seedling vigor of Fortune, clones should be crossed to a source with high seedling vigor and segregates with desirable turf characteristics progeny tested for seed weight and vigor index using open-pollinated progeny.

Summary for Seed and Seedling Vigor Phase

There were large differences among groups and individual S_1's and SX's for most characteristics studied with the exception of seed respiration. No SX or S_1 was equal to the check variety Fawn for most characteristics.

Among S_1's and SX's, S_1 1 had the heaviest seed and highest oxygen uptake. Seed of S_1 5 germinated faster and had longer shoots than other entries at seven and nine days. Single-cross 4x5 made the most early root and shoot growth (four days), while SX 1x2 had higher root and shoot growth rates from four to seven and seven to nine days than SX 4x5, resulting in longer total axis at seven and nine days. Single-cross 4x5 and S_1 5 were most efficient at converting seed weight to root length (root unit growth) while SX 2x10 and S_1 5 were usually most efficient at converting seed weight to shoot and total axis length.

Early S_1 and early x early SX groups were consistently superior to late S_1's and late x late SX's in seed and seedling vigor characteristics, while early x late SX's were intermediate.

Average performance of S_1's and SX's was very similar for most characteristics with the largest differences occurring in oxygen uptake and carbon dioxide evolution in which S_1's were high, and growth rate in which SX's were high.

Due to the low amount of variation in oxygen uptake and carbon dioxide evolution these characteristics were not too useful in separating entries, although both were associated with most other characteristics. Adjustment to a common germination percentage and seed weight resulted in still fewer detectable differences among entries for these characteristics. Respiration quotient (RQ) was of no value in distinguishing seed vigor differences. Measurements of respiration also required more labor and equipment than other measures of seed and seedling vigor.

Root length may be a better indication of early seedling vigor than shoot length because root growth precedes shoot growth, and because a large initial root shoot ratio was particularly evident in the vigorous check variety Fawn. Coefficients of variation were also lower for root length than shoot length.

Growth rate of root and shoot (fourth-seventh and seventh-ninth day) eliminates to a large degree the advantages of faster germination, therefore it is doubtful that selection on the basis of growth rate alone would be desirable.

Certain entries with lighter seed weight were favored for unit growth characteristics resulting in high rankings for two S_1's (S_1's 2 and 7) which ranked low for other seedling vigor characteristics, and usually resulted in low rankings for Fawn, which had the highest seedling vigor by most criteria.

Vigor index, which is a measure of speed of germination, and which requires less time and space than the other methods, may give as good an indication of seedling performance as root length at seven and nine days. Vigor index was not associated with seed weight but was significantly associated with root length and with all other measures of seedling vigor excluding shoot unit growth of S_1's. Vigor index also had the lowest coefficient of variation of any seedling vigor characteristic.

Most seedling vigor characteristics were significantly associated with from one to three mature plant characteristics, most often fall vigor rating. However, vigor index was not associated with any mature plant characteristic, therefore selection for increased seedling vigor on the basis of vigor index would not be expected to result in changes in the mature plant.

Three methods of selection for increased and decreased seedling vigor resulted in small differences between selected populations.

Associations of seed weight and vigor index between topcross and S_1 seed suggest that neither characteristic responds to heterosis. Single-cross and S_1 data from the seedling vigor phase also indicate a lack of heterosis for these characteristics.

Association of Forage and Seed Yield

Means for parents and each progeny group for two forage harvests, total forage yield, and seed yield are presented in Table 20, with individual means, standard errors of the mean, and coefficients of variation shown in Appendix Table 8. Mean squares and levels of significance are presented in Table 21.

Table 20. Mean[1] oven dry forage yield for two harvests, total forage yield, and seed yield for parents and five progeny groups of tall fescue. (Corvallis, Oregon. 1969)

Group	Forage yield (kg)			Seed yield (gm)
	Harvest 1	Harvest 2	Total forage	
Parents	.887	.703	1.580	360.50
S_1 progeny	.707	.548	1.255	272.83
OP progeny	.827	.749	1.576	351.81
PX progeny	.862	.745	1.607	327.11
SX progeny	.898	.709	1.606	340.17
F_2 progeny	.539	.443	.982	214.53

[1]Means are expressed on a per plot basis.

Single-cross progeny produced the most forage at the first harvest followed closely by the parents, with the F_2 progeny

Table 21. Mean squares and levels of significance for forage and seed yield of intermediate maturity group tall fescue. (Corvallis, Oregon. 1969)

Source of variation	d. f.	Forage yield: Harvest 1	Forage yield: Harvest 2	Forage yield: Total forage	Seed yield
Replications	3	.023	.143*	.113	33434.33**
Treatments	99	.170**	.103**	.459**	35397.12**
Among groups	5	1.860**	1.247**	6.062**	264002.60**
Within groups	94	.080**	.043**	.161**	23237.25**
Among parents	8	.155**	.043**	.269**	65629.25**
Among S_1	8	.138**	.130**	.443**	29721.25**
Among OP	8	.044	.009	.072	6617.86
Among PX	8	.078*	.009	.089	19319.70**
Among SX	35	.084**	.041**	.140**	21996.80**
Among F_2	27	.048	.039**	.119**	16448.52**
Error	297	.036	.015	.047	5387.99

*, ** Significant at the five and one percent level respectively.

considerably less productive than the other progeny groups. At the second forage harvest the F_2 progeny were again low, SX progeny and parents were intermediate, and the open-pollinated (OP) and polycross (PX) progeny had the highest yields. Parents, OP, PX, and SX progenies had very similar total forage yields with S_1 progeny intermediate and F_1 progeny lowest in yield.

Parents were higher in seed production than all progeny groups (Table 20). Open-pollinated and SX progeny were next in yield with S_1 and F_2 progeny lowest.

Generally there were significant differences among and within parents and progeny groups for both forage and seed yield (Table 21). Exceptions were among OP progeny in which there were no significant differences for forage or seed yield, and among PX progeny for the second forage harvest and total forage yield. There were no differences among F_2 progeny for the first forage harvest.

Total forage and seed yield were significantly associated in four of the five progeny groups (Table 22). The highest correlation occurred in the S_1 progeny (r = .794*) with the correlation in the F_2 progeny significant at the one percent level (r = .534**). Open-pollinated and SX progeny also showed significant associations of forage and seed yield, but in the parents (r = .561) and PX progeny (r = -.073) there was no association.

These results are in agreement with those of Burton and DeVane

Table 22. Simple correlation coefficients between seed and forage yield for parent clones and five progeny groups of intermediate maturity group tall fescue. (Corvallis, Oregon. 1969)

Number of entries	Group	Correlation coefficient
9	Parent	.561
9	S_1	.794*
9	OP	.672*
9	PX	-.073
36	SX	.365*
28	F_2	.534**

*, ** Significant at the one and five percent level respectively.

(1953) who found no association of forage and seed yield of clonal material, and Cowan (1955) who found a significant association between hay and pasture yield and seed yield of OP progeny. The significant association between forage and seed yield of SX progeny (r = .365*) does not agree with results of Echeverri (1964) who found no association in SX progeny (r = -.11).

Results of the present study may be more meaningful than those of previous studies because forage and seed yield were taken in the same season on the same (duplicated) populations.

The possibility of attaining high seed yield and high forage yield in the same clone is indicated because the two highest OP progenies for both forage and seed yield originated from the same two clones.

Despite the low correlation in PX's, the high PX progeny for forage yield was second in seed yield. The fairly high correlation of seed and forage yield in S_1 and F_2 progenies may indicate that both characteristics may be readily obtainable in inbred lines of tall fescue should breeders begin producing commercial hybrids. In this event the low but significant association of forage and seed yield in SX progeny would be of limited interest to the breeder.

SUMMARY AND CONCLUSIONS

Heterosis Phase

Tall fescue clones selected for diverse morphology, origin, and anthesis date were studied to determine if diversity results in increased heterosis for plant height, panicle number, early anthesis date, seed yield, and fall vigor rating. The nursery contained parents and first generation selfed (S_1) and single-cross (SX) progeny. Parents and S_1 progeny were classified according to anthesis date as early or late, with three types of SX progeny resulting from crosses among early, among late, and between early and late parents.

Entries were established in four replications and a randomized block design in September, 1969 at the Hyslop Agronomy Farm, Corvallis, Oregon. Each experimental plot consisted of 14 plants spaced three feet apart in a row with four feet between rows. Data were collected on plant height, panicle number, anthesis date, seed yield, and fall vigor rating during the summer and fall of 1970.

With few exceptions there were significant differences among and within groups for the five characteristics. The SX progeny were superior to parents except for seed yield, with parents performing better than S_1 progeny with the exception of plant height.

Average heterosis of SX's above the mid-parent was 15.36, 2.60, 28.21, 24.79, and 23.04 percent for plant height, early anthesis date, panicle number, seed yield, and fall vigor rating respectively. Average heterosis above the high-parent (HP) was expressed for panicle number (5.85 percent) and fall vigor rating (10.27 percent).

Crosses between maturity groups resulted in greater heterosis above the mid-parent than crosses within maturity groups for four of five characteristics. In relation to the high-parent, early x late SX's produced the most panicles (117.50 percent of HP), with early x early SX's tallest (106.49 percent of HP) and most vigorous (115.36 percent of HP).

Crosses to parents with very low vegetative vigor always resulted in progeny with more vegetative vigor than the high parent.

It appears that crosses between diverse parents will result in more frequent and larger degrees of heterosis than crosses among similar parents. Additional diversity by way of anthesis date appears to increase response to heterosis. However, it is doubtful that crosses between diverse clones could be made on a large scale.

Seed and Seedling Vigor Phase

Single-cross, first generation selfed (S_1), topcross, and open-pollinated seed and seedlings were tested for vigor using several methods. Characteristics were measured in the laboratory using a Gilson differential respirometer and a seed germinator.

There were significant differences among and within SX and S_1 groups for most seed and seedling vigor characteristics, with seed respiration characteristics (oxygen uptake, carbon dioxide evolution, respiration quotient) the most frequent exceptions.

The average performance of S_1's and SX's was very similar for most characteristics, with the largest differences occurring in oxygen uptake and carbon dioxide evolution in which S_1's were high, and in root growth rate in which SX's were high.

Early S_1 and early x early SX groups were consistently more vigorous than late S_1 and late x late SX groups. The early x late SX group was intermediate between early x early and late x late groups for all seedling vigor characteristics.

There was a high association between most seed and seedling vigor characteristics, in SX's and S_1's. However seed weight which was significantly associated with most vigor characteristics in the S_1 group was not associated with any vigor characteristic in SX's.

Root length at seven and nine days and vigor index (a measure of germination speed) were two of the better indicators of early seedling vigor. Selection on the basis of vigor index should be an effective laboratory method of screening for high seedling vigor in tall fescue. However, this method might be improved by further evaluation of those seeds which germinate rapidly, on the basis of subsequent root growth.

One cycle of selection for high and low seedling vigor by three methods (seed weight, head selection on shoot length, and emergence from deep seeding) resulted in small increases and decreases in seed weight and vigor index.

Positive associations of seed weight and vigor index between topcrosses and S_1's suggests a lack of appreciable heterosis for these characteristics. However, a lack of xenia would cause the same pattern of behavior.

Association of Forage and Seed Yield

An intermediate maturing group of tall fescue was used to study the association of forage and seed yield. During the spring and summer of 1969 data were taken from forage and seed yield nurseries, each containing the same parents and five progeny groups. These were: first generation selfed (S_1), open-pollinated (OP), polycross (PX), single-cross (SX), and selfed single-crosses (F_2). The nurseries were planted in a randomized block design with four replications.

Total forage and seed yield were significantly associated in four of five progeny groups with no association in parents and PX progeny. The highest correlation occurred in the S_1 progeny (r = .794*), while the correlation in the F_2 progeny was significant at the one percent level (r = .534**). Certain OP, PX, and SX progenies were high in both forage and seed yield indicating the possibility of attaining both characteristics in the same clone.

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APPENDICES

Appendix Table 1. Means[1], standard errors of the mean ($s\bar{x}$), and coefficients of variation (C. V.) for five characteristics in tall fescue heterosis study. (Corvallis, Oregon. 1970)

	Plant height, May 5 (cm)	Anthesis date, days after May 20	Panicle number	Seed yield	Fall vigor rating, Nov. 24[2]
			Parents		
P_1	86.21	4.18	32.31	23.71	2.78
P_2	75.78	4.75	27.82	11.28	2.86
P_3	78.37	6.22	34.21	13.07	3.07
P_4	59.64	10.82	29.48	13.63	3.63
P_5	66.17	11.13	27.16	14.85	2.75
P_7	50.96	17.05	30.63	.68	4.32
P_8	25.16	25.96	31.93	1.24	4.88
P_9	22.00	32.47	4.71	.11	5.77
P_{10}	11.19	40.71	20.57	.06	5.09
			S_1 progeny		
1	87.90	4.91	28.42	15.60	2.25
2	53.93	6.61	15.28	1.01	4.09
3	73.64	6.95	25.64	3.16	3.61
4	58.93	12.88	36.48	6.77	3.52
5	66.67	13.50	22.92	10.14	3.37
7[a]	44.91	20.80	20.77	.17	4.93
8	26.09	27.80	28.64	.59	5.12
10	16.30	42.12	20.24	.13	5.23
			SX progeny		
1x2	84.04	5.25	30.91	21.27	2.25
2x3	81.19	5.86	32.45	14.03	2.68
4x5	78.33	14.06	41.05	23.48	2.18
7x8	43.02	21.22	38.87	.16	3.95
8x9	27.15	29.54	23.35	.88	4.49
9x10	17.29	37.44	15.75	.34	4.70
3x8	64.16	13.13	45.81	.23	2.62
1x9	64.02	13.30	19.25	8.23	2.68
2x10	56.56	15.24	44.24	6.40	2.75
Check[b]	99.08	5.82	40.80	35.99	1.82
Grand mean	56.81	16.43	28.80	8.73	3.56
$s\bar{x}$	5.89	.78	2.69	1.53	.17
C. V.	20.74	9.50	18.17	35.10	9.25

[1]Means are expressed on a per plant basis.
[2]Fall vigor rated 1-7; 1 equals the most vigorous.
[a]Only one replication established. [b]Variety Fawn.

Appendix Table 2. Mean squares and levels of significance for five seed vigor characteristics of tall fescue. (Corvallis, Oregon. 1970)

Source of variation	d.f.	Percent germination	Seed weight	Oxygen uptake	Oxygen uptake adjusted for germination	Oxygen uptake adjusted for germination and weight
Treatments	16	241.765**	1425.028**	31.698**	29.806*	31.914
Among groups	2	67.134	2124.375**	147.701**	129.194**	105.501**
Within groups	14	266.712**	1325.121**	15.126*	15.608	21.401
Among SX	8	422.889**	734.138**	14.115	16.796	27.235
Among early x early	2	14.000	1279.707**	4.084	3.207	6.026
Among late x late	2	1320.667**	254.625**	.008	32.743	45.700
Among early x late	2	52.667	1147.335**	5.162	2.701	22.907
Among maturity groups	2	304.222**	254.884**	47.206**	28.536	34.307
Among S_1	6	58.476	2113.100**	16.474*	14.022	13.622
Among early	4	50.600	2207.619**	18.200*	17.080	.678
Among late	1	49.000	138.062*	12.960	9.363	50.339
Among maturity groups	1	99.457*	3710.061**	13.085	6.446	28.684
Error	17	22.118	16.840	6.058	9.639	16.817

*, ** Significant at the five and one percent level respectively.

Appendix Table 3. Mean squares and levels of significance for five seed vigor characteristics of tall fescue. (Corvallis, Oregon. 1970)

Source of variation	d. f.	CO_2 evolution	CO_2 evolution adjusted for germination	CO_2 evolution adjusted for germination and weight	R. Q.	Vigor index
Treatments	16	22.362**	21.326**	21.912	.0116	2.042**
Among groups	2	84.787**	73.702**	63.973*	.0009	1.992**
Within groups	14	13.444**	13.843	15.903	.0131	2.050**
SX	8	13.721**	15.224	21.395	.0216	2.792**
Early x early	2	5.407	4.413	1.097	.0035	.708*
Late x late	2	1.972	20.769	27.160	.0467*	.582**
Early x late	2	5.852	4.637	17.699	.0170	1.246**
Among SX	2	41.654**	31.077*	39.625*	.0194	3.400**
S_1	6	13.075*	12.003	8.581	.0018	1.059**
Early	4	14.852*	14.952	1.687	.0025	.741**
Late	1	7.840	5.712	31.472	.0004	1.651**
Among S_1	1	11.201	6.497	13.269	.0004	1.741**
Error	17	3.623	6.210	10.842	.0121	.155

*,** Significant at the five and one percent level respectively.

Appendix Table 4. Mean squares and levels of significance for six seedling vigor characteristics of tall fescue. (Corvallis, Oregon. 1970)

Source of variation	d.f.	Root length			Shoot length		
		4 days	7 days	9 days	4 days	7 days	9 days
Treatments	16	.3393**	1.3537**	2.6841**	.0443**	.8229**	2.4836**
Among groups	2	.6665**	3.5691**	6.5710**	.0155	.6862*	2.6348**
Within groups	14	.2926**	1.0372**	2.1289**	.0485**	.8424**	2.4620**
SX	8	.4274**	1.1280**	2.0001**	.0645**	1.1803**	3.6571**
Early x early	2	.2300**	.8740**	1.4550**	.0413*	.5485*	.4142
Late x late	2	.2875**	1.1012**	2.6534**	.0101	..7733**	4.9394**
Early x late	2	.1255**	.2034**	.0036	.0562**	1.6301**	4.3050**
Among SX	2	1.0664**	2.3332**	3.8884**	.1504**	1.7695**	4.9698**
S_1	6	.1129**	.9161**	2.3005**	.0271*	.3918*	.8686**
Early	4	.1167**	.6335**	1.3956**	.0348**	.4256*	.7741**
Late	1	.0030	.0016	.0025	.0004	.0256	.0870
Among S_1	1	.2075**	2.9610**	8.2183**	.0231	.6231*	2.0280**
Error	17	.0141	.0860	.1703	.0070	.1174	.1258

*,** Significant at the five and one percent level respectively.

Appendix Table 5. Mean squares and levels of significance for six seedling vigor characteristics of tall fescue. (Corvallis, Oregon. 1970)

Source of variation	d.f.	Length of total axis			Root growth rate/day		Shoot growth rate/day
		4 days	7 days	9 days	4th-7th day	7th-9th day	4th-7th day
Treatments	16	.5410**	3.8501**	9.1660**	.0515**	.0652**	.0648**
Among groups	2	.5658**	7.6363**	17.5618**	.1346**	.1137**	.0761**
Within groups	14	.5375**	3.3092**	7.9666**	.0397**	.0583**	.0632**
SX	8	.8035**	4.2223**	10.0112**	.0374**	.0341*	.0915**
Early x early	2	.4662**	2.7567**	3.3965**	.0259*	.0087	.0396*
Late x late	2	.4027**	3.7291**	14.7691**	.0666**	.0145	.0775**
Early x late	2	.3416**	2.4540**	4.4856**	.0005	.1050**	.1317**
Among SX	2	2.0036**	7.9493**	17.3934**	.0566**	.0082	.1171**
S_1	6	.1828**	2.0917**	5.2405**	.0426**	.0906**	.0254
Early	4	.1819**	1.6505**	3.2442**	.0223*	.0717**	.0266
Late	1	.0049	.0400	.0625	.0042	.0196	.0006
Among S_1	1	.3641**	5.9081**	18.4041**	.1625**	.2370**	.0457
Error	17	.0308	.3240	.4827	.0049	.0106	.0104

*,** Significant at the five and one percent level respectively.

Appendix Table 6. Mean squares and levels of significance for six seedling vigor characteristics of tall fescue. (Corvallis, Oregon. 1970)

Source of variation	d.f.	Shoot growth rate/day 7th-9th day	Total axis growth rate/day 4th-7th day	Total axis growth rate/day 7th-9th day	Root unit growth 4 days	Root unit growth 7 days	Root unit growth 9 days
Treatments	16	.1152**	.2006**	.2360**	.4411**	.4373**	.4722**
Among groups	2	.1610**	.4025**	.5338**	.3076**	.4754**	.4989**
Within groups	14	.1086**	.1718**	.1935**	.4601**	.4318**	.4684**
SX	8	.1745**	.2225**	.2087**	.7252**	.5919**	.5690**
Early x early	2	.0078	.1260**	.0067	.2202**	.0705	.0394
Late x late	2	.4098**	.2861**	.5710**	.5730**	.8215**	1.1062**
Early x late	2	.1266**	.1509**	.0205	.4843**	.5780**	.2368*
Among SX	2	.1536**	.3272**	.2369*	1.6231**	.8977**	.8937**
S_1	6	.0209	.1040**	.1731**	.1068*	.2183*	.3342**
Early	4	.0189	.0605*	.1307*	.1410**	.1953*	.2198*
Late	1	.0004	.0016	.0144	.0380	.0380	.0156
Among S_1	1	.0490	.3806**	.5016**	.0388	.4909*	1.1107**
Error	17	.0151	.0187	.0417	.0278	.0602	.0536

*,** Significant at the five and one percent level respectively.

Appendix Table 7. Mean squares and levels of significance for six seedling vigor characteristics of tall fescue. (Corvallis, Oregon. 1970)

Source of variation	d.f.	Shoot unit growth			Total axis unit growth		
		4 days	7 days	9 days	4 days	7 days	9 days
Treatments	16	.1052**	.5061**	.9398**	.8358**	1.6380**	2.3614**
Among groups	2	.0761*	.0597	.0730	.2139	.8086	.8595*
Within groups	14	.1093**	.5699**	1.0636**	.9246**	1.7564**	2.5759**
SX	8	.1216**	.7705**	1.5565**	1.3963**	2.4342**	3.7592**
Early x early	2	.0451	.0466	.0481	.4588**	.2027	.0168
Late x late	2	.0216	.5433*	1.9012**	.8088**	2.7346**	5.8714**
Early x late	2	.1713**	1.6428**	2.8314**	1.2080**	3.5246**	4.6885**
Among SX	2	.2483**	.8494**	1.4452**	3.1094**	3.2752**	4.4600**
S_1	6	.0930**	.3025*	.4065**	.2958**	.8527*	.9983**
Early	4	.1358**	.4272*	.5600**	.4061**	1.0661*	1.1032**
Late	1	.0049	.0784	.1936	.0702	.2209	.3192
Among S_1	1	.0096	.0274	.0053	.0802	.6311	1.2578*
Error	17	.0136	.0940	.0545	.0614	.2392	.1726

*, ** Significant at the five and one percent level respectively.

Appendix Table 8. Means, standard errors of the mean (s$\bar{x}$), and coefficients of variation (C. V.) for forage and seed yield of intermediate maturity group tall fescue. (Corvallis, Oregon. 1969)

Clonal identification	Forage yield (kg) Harvest 1	Harvest 2	Total forage	Seed yield (gm)
		Parents		
2960	.919	.821	1.740	567.25
2980	.949	.671	1.620	321.50
2990	1.045	.677	1.722	378.00
3110	.923	.574	1.497	499.25
3290	.878	.784	1.662	382.25
3590	.782	.661	1.443	178.75
3660	1.167	.780	1.947	351.50
3680	.469	.542	1.011	178.50
3740	.762	.821	1.583	387.50
Average	.877	.703	1.580	360.50
		S_1 progeny		
2961	1.003	.826	1.828	348.00
2981	.648	.720	1.368	332.25
2991	.786	.546	1.332	346.75
3111	.520	.281	.801	190.00
3291	.806	.595	1.401	331.75
3591	.512	.379	.891	132.00
3661	.554	.654	1.208	175.75
3681	.587	.353	.940	256.00
3741	.948	.580	1.528	343.00
Average	.707	.548	1.255	272.83
		OP progeny		
2962	.934	.841	1.775	405.75
2982	.947	.723	1.669	319.00
2992	.809	.791	1.600	362.00
3112	.952	.771	1.723	425.00
3292	.823	.697	1.520	327.50
3592	.698	.695	1.392	300.75
3662	.775	.733	1.508	336.75
3682	.665	.736	1.400	356.25
3742	.845	.753	1.598	333.25
Average	.827	.749	1.576	351.81

(Continued on next page)

Appendix Table 8. (Continued)

Clonal identification	Forage yield (kg) Harvest 1	Harvest 2	Total forage	Seed yield (gm)
		PX progeny		
2963	.972	.793	1.766	372.00
2983	.677	.746	1.423	332.00
2993	.854	.690	1.544	485.75
3113	1.071	.684	1.754	276.50
3293	.946	.786	1.732	320.75
3593	.918	.729	1.647	310.25
3663	.907	.792	1.698	293.75
3683	.653	.699	1.352	310.50
3743	.761	.788	1.549	242.50
Average	.862	.745	1.607	327.11
		SX progeny		
366x368	.748	.678	1.426	369.75
366x374	.729	.546	1.275	275.50
368x374	.750	.720	1.470	367.75
311x329	.776	.597	1.373	291.50
311x359	1.079	.744	1.822	265.50
311x366	.691	.732	1.423	299.50
299x359	1.016	.661	1.677	373.50
299x329	.881	.653	1.533	369.00
299x311	1.281	.577	1.858	464.25
359x374	.831	.531	1.362	236.25
359x368	.862	.672	1.533	306.00
359x366	.732	.696	1.428	165.75
299x366	1.039	.811	1.849	407.75
299x368	.903	.570	1.473	436.75
299x374	1.000	.814	1.814	510.50
311x368	.868	.631	1.499	322.00
311x374	.868	.786	1.654	319.25
329x359	.932	.715	1.647	373.25
296x366	.705	.843	1.549	345.75
296x359	.908	.780	1.688	324.50
296x329	1.267	.774	2.042	429.35
329x374	.955	.752	1.706	349.50
329x368	.877	.737	1.614	320.00
329x366	.878	.833	1.711	345.25
298x299	.886	.666	1.552	379.50

(Continued on next page)

Appendix Table 8. (Continued)

Clonal identification	Forage yield (kg) Harvest 1	Forage yield (kg) Harvest 2	Total forage	Seed yield (gm)
		SX progeny (continued)		
298x311	.934	.665	1.598	345.00
298x359	.831	.480	1.311	263.00
298x329	1.103	.880	1.983	298.50
298x366	.887	.769	1.656	357.00
298x368	.808	.700	1.508	248.25
296x368	.678	.685	1.363	317.50
296x374	.840	.656	1.496	431.70
298x374	.770	.879	1.649	283.25
296x311	1.047	.621	1.668	464.00
296x299	.941	.844	1.785	390.00
296x298	1.016	.820	1.835	215.30
Average	.898	.709	1.606	340.17
		F_2 progeny		
366x368	.388	.501	.889	286.75
366x374	.323	.517	.840	183.25
368x374	.581	.431	1.012	271.50
311x329	.572	.593	1.165	288.00
311x359	.526	.397	.923	187.75
311x366	.409	.333	.742	274.25
299x359	.783	.580	1.363	453.25
299x329	.363	.373	.736	210.75
299x311	.533	.408	.941	179.25
359x374	.613	.567	1.180	213.50
359x368	.429	.313	.741	138.75
359x366	.514	.347	.861	140.25
299x366	.526	.486	1.012	184.50
299x368	.487	.286	.773	152.00
299x374	.712	.413	1.125	228.00
311x374	.635	.503	1.138	228.25
329x359	.611	.128	.988	239.00
296x366	.446	.444	.890	166.50
296x359	.627	.397	1.024	175.25
296x329	.622	.443	1.065	176.50
329x374	.509	.341	.849	209.50
329x368	.522	.367	.888	234.00
329x366	.667	.751	1.418	248.00
298x299	.650	.439	1.089	184.75

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Appendix Table 8. (Continued)

Clonal identification	Forage yield (kg) Harvest 1	Harvest 2	Total forage	Seed yield (gm)
	F_2 progeny (continued)			
298x359	.610	.458	1.068	211.75
296x374	.481	.456	.937	195.00
298x374	.496	.478	.974	180.25
296x299	.485	.395	.854	169.75
Average	.539	.443	.982	214.53
Alta	1.061	.724	1.785	308.50
Grand mean	.769	.626	1.395	300.59
$s\bar{x}$	.095	.061	.108	36.70
C.V.	24.68	19.65	12.57	24.42