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CONJE, Jr., Ambrocio Mendez, 1940-
PERFORMANCE OF CROSSES WITHIN AND BETWEEN TWO DIVERSE SOURCES OF BIRDSFOOT TREFOIL, *LOTUS CORNICULATUS* L.

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Performance of crosses within and between two diverse sources of birdsfoot trefoil, *Lotus corniculatus*, L.

by

Ambrocio Mendez Conje, Jr.

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INTRODUCTION

Birdsfoot trefoil, Lotus corniculatus L., is a perennial forage legume of increasing importance in the United States. Reports published in "Trends in Forage Crop Varieties" (Saunders et al., 1969) indicate that the total acreage in birdsfoot trefoil increased from 770,000 acres in 1957 to slightly over 2 million acres in 1967. Wedin et al. (1967) estimate that there are 30 million acres of unproductive pasture in the midwestern states and 10 million in the Northeast. On much of this acreage, birdsfoot trefoil would be well adapted as a permanent pasture legume. Research to reduce establishment hazards and to develop improved varieties of birdsfoot trefoil should result in the continued rapid expansion of this important legume in permanent pasture.

In many species of both plants and animals, heterosis has resulted from crosses between populations (Wallace, 1955; Lonnquist and Gardner, 1961; Sriwatanapongse and Wilsie, 1968). Therefore, some improvement programs are designed to select and test parent populations for inclusion in population crosses. Improvement programs in birdsfoot trefoil have been concerned primarily with phenotypic mass selection followed by random crossing of the selected clones. Recurrent selection programs, with selection based on either phenotypic performance or a progeny test, also have been used to a limited extent. In most cases, materials used in these programs represented a rather narrow range of genetic variability. The association between heterosis and genetic diversity over a wider range of variability has become particularly important with increasing interest in the introduction of foreign germplasm into breeding programs for birdsfoot trefoil.

Genetic differences between varieties have probably arisen through geographical isolation accompanied by a combination of genetic drift and selection in different environments. Therefore, the degree of geographical separation and the degree of ancestral relationship, insofar as it is known, can be used as indicators of genetic diversity.

Nine clones derived from a local cultivar and nine clones derived from intercrosses of selections from two Russian introductions were chosen for this study. Crosses within and between these two diverse sources were made with the following objectives: (1) to evaluate the influence of genetic diversity on the expression of heterosis and to determine the effect of intra- and intervarietal hybridization on seed size and progeny seedling vigor; (2) to study general and specific combining ability of the parent clones; (3) to study the interrelationships among characters that affect forage yield, seed size and seed load; and (4) to select clones with good combining ability for inclusion in a recurrent selection program.

LITERATURE REVIEW

Distribution and Use of *Lotus* Species

The genus *Lotus* consists of a diverse group of annual and perennial species widely distributed throughout the world. Depending upon the system of classification, there are approximately 80 or up to 200 different species in the genus (Isely, 1951; Zandstra and Grant, 1967). The greatest diversity of species is found in the Mediterranean basin, an indication that this area was probably the center of origin for the Old World species. Species endemic to North America extend along the West Coast from British Columbia to Mexico and Lower California.

Three perennial trefoil species are used for forage production in the United States. The most important of the three, birdsfoot trefoil, *Lotus corniculatus* L., is extensively grown for pasture and hay in North Central and Northeastern United States and Eastern Canada. Narrowleaf trefoil, *L. tenuis* Wald et Kit., is an important pasture legume on heavy, imperfectly drained soils in New York, California and Oregon. Big trefoil, *L. pedunculatus* Cav., because of susceptibility to certain diseases and lack of tolerance to drought, is used only to a limited extent. It is used on low-lying coastal soils of the Southeast (Seany and Henson, 1970).

The work reported in this study deals only with cultivars of *L. corniculatus* L.

Origin, Cytology and Inheritance, *L. corniculatus*

L. corniculatus is a tetraploid with 2N = 24 chromosomes. Chromosome pairing is usually bivalent with the occurrence of an occasional quadrivalent. Frequency of quadrivalent pairing is about 1 quadrivalent in every 4 microspore mother cells (Wernsman et al., 1964).

Dawson (1941) and others suggested that *L. corniculatus* is an autotetraploid of *L. tenuis*. This conclusion was based on the chromosome number of these species (*L. tenuis*, 2N = 12), their morphological characteristics and tetrasomic inheritance of cyanogenesis. From an analysis of phenolic constituents, Harney and Grant (1965) indicated that *L. corniculatus* is more likely an allotetraploid than an autotetraploid. Grant and Sidhu (1967) interpreted their data on HCN reaction of species in the *Lotus* group to indicate that other species, as well as *L. tenuis*, could be ancestors of the tetraploid *L. corniculatus*. Other evidence that *L. tenuis* is a progenitor of *L. corniculatus* is found in the work of Wernsman et al. (1964). Interspecific hybrids of 4x *L. tenuis* x *L. corniculatus* usually formed 12 chromosome pairs at meiosis, although an occasional quadrivalent was found. Backcross progenies of interspecific hybrids x parental species showed bivalent pairing, indicating that the chromosomes of *L. tenuis* and *L. corniculatus* possess a high degree of homology.

Tetrasomic inheritance has been shown for certain characters in birdsfoot trefoil. Dawson (1941) found that cyanogenesis in *L. corniculatus* is determined by a single dominant gene inherited tetrasomically. The acyanogenetic plants, which are homozygous recessive, lack the enzyme which is necessary for hydrolysis of the cyanogenetic glucoside. The concentration of hydrocyanic acid is probably determined by a series of modifying genes. Donovan and McLennan (1964), working with crosses between the large leaved *L. corniculatus* var. *vulgaris* and small leaved *L. corniculatus* var. *arvensis*, found large leaf to be dominant with an autotetraploid type of inheritance. Chlorophyll content in the variety Viking was found by Pootschi and MacDonald (1961) to be determined by a single dominant gene showing random, four-chromosome type of segregation. In certain accessions of *L. corniculatus*, keel tip color may be yellow, brown or red. Both brown and red keel tip are dominant to yellow (Bubar and Miri, 1965; Buzzell and Wilsie, 1963; Hart and Wilsie, 1959). Brown keel tip is determined primarily by a single gene, with tetrasomic inheritance. Other characters in trefoil which show tetrasomic type of inheritance are pubescence, streaks on the corolla, and self-incompatibility (Bubar and Miri, 1965).

Inheritance studies on flowering time and length of flowering stem in crosses between Empire and Viking varieties were made by Buzzell and Wilsie (1965). Dominance for early flowering was related to the flower stem length of the parent plants. Dominance of early flowering was found in crosses involving early by late flowering and short by short stem length. Little or no dominance was observed in crosses involving early by late flowering and short by long stem length.

Heterosis and Genetic Diversity

In many species of plants, heterosis has resulted from crosses between highly divergent plant types or among widely divergent sources of germplasm. In alfalfa, Westgate (1910) found that the variegated alfalfa hybrids from the cross *Medicago falcata* x *M. sativa* performed better than both parents. In two crosses involving erect and prostrate alfalfa clones, Wilsie (1958) found a striking degree of heterosis with the F_1 hybrids yielding as high as 81 percent above the level of the high yielding parent. In rye, Hagberg (1952) found that under space-planted conditions, the grain production of intervarietal crosses of diploid rye varieties ranged from 2 to 17 percent above the superior parent. Evidence of hybrid vigor in birdsfoot trefoil as indicated by increased forage yields of F_1 hybrids over that of the midparent has been obtained by Mr. N. C. Lawson at MacDonald College, Canada (unpublished work).

In more recent years, interest in the introduction of exotic stocks into breeding programs to increase genetic variability has developed. In trefoil, Bent (1962) attempted interspecific crosses in order to introduce into *L.*

corniculatus the superior seedling vigor of L. tenuis and the rhizomatous and delayed shattering characteristics of L. pedunculatus. Plant characteristics of the interspecific hybrids, such as leaf size and shape and number of flowers per umbel, were intermediate between the parent species. Bent was successful in isolating the delayed pod shattering and rhizomatous characteristics of L. pedunculatus in advanced-generation populations of the interspecific cross. Wernsman et al. (1964) found that crosses of L. corniculatus with both diploid and tetraploid plants of L. tenuis were vigorous, intermediate in appearance, and show a relatively high degree of fertility when intercrossed. Grant (1965) has catalogued all interspecific crosses between Lotus species. Within the genus Lotus, a relatively large number of successful interspecific crosses have been made. However, L. corniculatus has been successfully crossed with only four other species, L. tenuis, L. pedunculatus (both 2X and 4X), L. palustris, and L. coimbrensis.

In corn, initial studies attempted to relate diversity of origin to heterotic response observed. Wellhausen (1952) recorded the responses of F_1's among a large number of diverse Mexican races. The heterotic responses ranged from large positive effects down to performance below either parent variety. Lonnquist and Gardner (1961) found that intervarietal crosses among 12 parents, representing a range of Corn Belt germplasm, produced mean F_1 yields above the midparent value.

Paterniani and Lonnquist (1963) obtained similar results from 63 F_1 crosses among South American races of maize. Moll, Salhuana and Robinson (1962) examined the performance of 15 crosses of six varieties representing three widely dispersed geographical regions. They found that greater genetic diversity of the parental varieties is associated with greater heterosis in the variety cross. The highest yielding crosses involved parental varieties from different regions.

Hagberg (1952) found a heterotic effect on grain yield when he compared crosses between populations of rye which were slightly inbred with crosses between plants within populations. High heterosis was associated with the greater genetical differentiation between parent populations. Crosses between different populations of red clover, however, did not show a similar relationship. His explanation was that the genetical variation within these populations was probably greater, in comparison with the differentiation between populations, than was the case in the rye populations.

In a theoretical study, Cress (1966) was of the opinion that genetic divergence (difference in gene frequency) of the parents is required for heterosis to be manifest in the cross. However, the lack of heterotic response cannot be used to infer a lack of genetic divergence. He reasoned that the negative heterotic contributions at certain loci cancel positive responses at other loci. The net response in the hybrid may be little or no deviation from the midparent. Thus, the validity of evaluating the degree of genetic divergence based on the amount of heterotic response is subject to considerable question.

General and Specific Combining Ability

The importance of testing materials for combining ability prior to the production of hybrid and synthetic varieties has been recognized. Kehr and Graumann (1958) defined combining ability as the performance of a clone or line in combination with other clones or lines. It is the ability of a given selection to transmit to its progenies the traits for which it has been selected.

Sprague and Tatum (1942) presented a method of estimating general and specific combining ability for yield of single crosses of corn. General combining ability was used to designate the average performance of a line in hybrid combinations. Specific combining ability was used to designate those cases in which certain combinations did relatively better or worse than expected on the basis of average performance of the lines involved. They pointed out that, in a population unselected for combining ability, genes with additive effects (general combining ability) are either more common or produce greater effects than genes with dominance or epistatic effects (specific combining ability). However, in materials previously selected for general combining ability, dominance and epistatic effects are more noticeable than additive effects since remaining lines have a higher degree of similarity in performance than the original population.

The recognition of combining ability as an important factor in the selection of plants and inbred lines in corn has stimulated considerable interest in the possibilities of selection in other cross-pollinated crops on a similar basis. In forage crops, studies of combining ability have been quite extensive in alfalfa but very little work has been reported for trefoil.

Peacock and Wilsie (1957) studied resistance to seed pod shattering in trefoil. They found that the two clones which showed the best general combining ability for shattering resistance produced the best two-clone cross for that characteristic. In another study, Peacock and Wilsie (1960) found similar results for forage and seed yield.

Draper and Wilsie (1965) compared the relative importance of general versus specific combining ability for seed size in trefoil. Analysis of diallel crosses in two varieties, Empire and Viking, showed that the major part of the sum of squares due to crosses was attributable to general combining ability, suggesting the importance of additive genetic variance for seed size.

Miller (1968) studied the combining ability of four selected trefoil clones in a diallel cross. He found significant mean squares for general combining ability for flowering date and forage yield. Mean squares for specific combining ability were significant for flowering date, vigor score, disease score, and forage yield. Miller suggested that the presence of more general combining than specific combining ability variance for forage yield in his diallel indicated that emphasis should be placed on development of synthetic varieties rather than hybrids. He indicated that this situation might be different for other clones. In another study, Miller (1969) found that seed weight and percentage of successful crosses were influenced by general combining ability effects. No specific combining ability effects were noted.

In alfalfa, Morley et al. (1957) used the diallel method of crossing to evaluate 10 alfalfa strains which differed in winter and summer growth rates. The strains were found to differ with respect to combining ability for growth rates in both summer and winter but differences between strains were much more evident in winter than in summer.

Kehr and Graumann (1958) presented data from a diallel series of crosses among six selected alfalfa clones which showed quite high and similar general combining ability estimates for forage yield. In individual crosses, two of the clones exhibited high specific combining ability for forage yield.

Carnahan et al. (1959) reported on seedling vigor and fall growth habit of 91 single crosses of 14 alfalfa clones. As a group, the clones had not been selected previously for vigor and fall growth habit, but they were not considered a random sample from an alfalfa population at equilibrium. Estimated general combining ability components were much larger than specific combining ability components for both characters.

Elling et al. (1959) found that the variance component for general combining ability was six times that for specific combining ability for winterhardiness, although both combining ability variances were highly significant.

A diallel series of crosses in alfalfa was analyzed by Kehr (1961) for fall growth habit, rate of recovery, spring growth habit and forage yield. Estimated variance components for general combining ability were significant for fall growth habit and rate of recovery but not for spring growth habit nor forage yield. Estimated variance components for specific combining ability were significant for all traits measured. His results for spring growth habit and forage yield supported the idea that specific combining ability is more important than general combining ability in materials previously selected for general combining ability.

Frakes et al. (1961b) used data from diallel crosses of 2 upright and 2 prostrate genotypes of alfalfa to estimate general and specific combining ability for dry matter yield and components of yield (natural height, longest stem, natural width, and stem number). Diallel analysis showed that general combining ability effects were larger than specific combining ability effects for natural height and length of longest stem, but relatively small for natural width and number of stems per plant. Dry matter yield was intermediate among the four components in respect to relative magnitude of general and specific effects. The study showed that two components, natural height and longest stem, lend themselves to synthetic breeding, whereas the other two are better suited to a hybrid breeding program designed to take advantage of gene interaction.

Theurer and Elling (1963a, 1963b, 1964) reported on the diallel analysis of F_1 crosses among five diverse clones of alfalfa in a series of three publications. All five clones were resistant to bacterial wilt but differed considerably in winterhardiness, persistence and forage yield. The 10 single crosses, 26 possible Syn-2 generation synthetics, and the S_1 progenies were evaluated. All of the entries were highly resistant to bacterial wilt (Theurer and Elling, 1963a). The best single-cross was not significantly more resistant than the better synthetic varieties. The general combining ability variance of the five clones was considerably larger than that for specific combining ability, suggesting that rapid progress could be made for wilt resistance by combining clones having high general combining ability. For winterhardiness and persistence, the best entry was a single cross (Theurer and Elling, 1963b); however, the advantage of the single cross was not great enough to be a practical advantage over synthetic varieties. As expected, the variability in forage yield was greatest for the single cross class (Theurer and Elling, 1964). In the Syn-2 generation, the variability decreased as the number of clones in synthetics increased.

Buker (1963) studied the general and specific combining ability of eight alfalfa clones. The clones were selected from a population of 114 phenotypically superior plants and they were crossed in all possible combinations. Progenies were evaluated in both spaced and drilled plots. All of the statistical tests for general combining ability were significant and about two-thirds of those for specific combining ability were significant. It was suggested that in the population represented by these clones breeding systems which utilize both general and specific combining ability should be most effective.

Wilcox and Wilsie (1964) crossed nine alfalfa clones, selected in six North Central states, in a diallel manner to obtain estimates of general and specific combining ability of the parent clones. Reciprocal crosses were grown separately to provide an estimate of reciprocal effects. Diallel analysis indicated a high degree of variance (.01 level) for general combining ability effects for fall growth habit, forage yield, and spring vigor. Specific combining ability effects were significant (.01 level) for fall growth habit and spring vigor, and significant (.05 level) for forage yield. Reciprocal effects were evident for fall growth habit and yield. They mentioned the usefulness of diallel analysis in the selection of clones for hybrid combinations as well as synthetic varieties.

Daday (1965) investigated the genetic control of forage yield in alfalfa by a combining ability analysis of a diallel cross of nine genotypes. Summer forage yield was found to be controlled by additive and non-additive genes, and winter yield mainly by additive genes. General combining abilities differed markedly among genotypes for both summer and winter yields.

Rice and Gray (1969) made a diallel cross, including reciprocals, among 11 random clones of Buffalo alfalfa to investigate seed set differences. Seeds per pod, seeds per flower, and percentages of flowers forming pods were measured for each cross and its reciprocal. Diallel analysis revealed significant general, specific, and maternal effects for each character. Significant reciprocal effects were detected for seeds per flower and percentages of flowers forming pods. Specific effects made the largest contribution to variance for seeds per pod and seeds per flower, while general effects were the largest contributor to the variance for percentages of flowers forming pods.

Character Associations

Considerable emphasis has been placed on breeding trefoil for improved forage and seed yield. A knowledge of interrelationships among characters that affect forage and seed yield may lead to more effective methods for the simultaneous improvement of both traits.

Hulewicz (1961) examined some morphological characters and their interrelationships in tetraploid (2N = 24) and octoploid (2N = 48) forms of birdsfoot trefoil. Correlation analysis revealed a significant positive correlation between leaflet length and components of seed yield in tetraploids, whereas a negative association exists between these characters in the octoploids. Forage yield was positively correlated with its components (shoot number and thickness, length and number of internodes) in both forms. A similar positive relationship was found between seed yield and its components (number of inflorescences, pod weight, and number of seeds per pod). A significant positive correlation coefficient was also obtained between forage and seed yield, indicating possibilities of simultaneous improvement of both traits.

Miller (1968) studied the interrelationships of six variables in birdsfoot trefoil by means of simple correlation coefficients and multiple regression. Yield was significantly correlated with good vigor, low disease score, and early flowering date. Low disease score was also highly associated with high survival rate. No significant correlation was found between growth type and yield or flowering date. Multiple regression showed that most of the variation in yield was related to vigor rather than to other characters.

Most studies on the relationship between plant characters in forage legumes have been made on alfalfa. Tysdal and

Kiesselbach (1944) stated that high-yielding plants were taller, more upright, and more sparsely leaved, and they had thicker and more woody stems than low-yielding plants, though these characters do not show complete linkage.

Burton (1937) studied the relationship between total plant yield and various morphological characters in an F_2 population from a cross between Medicago sativa and M. falcata. He obtained positive correlation ratios of plant yield with plant height, leaf area index, stem length, length of new shoots, and the date of second bloom. Total yield was negatively correlated with leaf shape index.

Frakes et al. (1961a) studied the relationships between dry matter yield per plant and other associated characters in a space-planted alfalfa nursery consisting of S_1's, F_1's, F_2's and vegetatively propagated parents having prostrate or upright growth habit. The path-coefficient analysis of correlation coefficients showed natural plant width to be primarily direct in its effect on yield, whereas stem number was primarily indirect via leaf weight and stem weight. A large portion of the significant association of height and long stem length with yield was indirect in its effect via width.

Dudley and Hanson (1961) studied the correlations among several characters in F_2 populations derived from crosses between three creeping-rooted alfalfa clones and 19 hay-type clones. Highly significant positive correlations were found among height, spring growth and recovery, between plant width and yield, between leaf width and leaf length, and between crown width and procumbence. These correlations were significant for three sources of variation, i.e., variation associated with hay-type parents, F_1 plants within crosses measured on F_2 population, and plants within plots.

Nielsen and Mortensen (1963) investigated the interrelationships among various characters in alfalfa and reported that, in spaced plantings of clones and various types of crosses, height was closely correlated with vigor. Fairly close correlations were found also between seed yield and seed set and between seed set and date of termination of flowering.

Liang and Riedl (1964) found by computing simple correlation coefficients that plant height, number of leaves, number of internodes, and number of stems were positively correlated with forage yield. Plant height, seed size, fertility, and number of stems were positively correlated with seed yield.

Winterhardiness in alfalfa has been studied by several investigators. Blinn (1911) reported that hardy strains of alfalfa appeared to have a spreading type of crown, whereas non-hardy strains possessed a more upright crown. Smith (1961) found similar results. Elling et al. (1959) reported a highly significant correlation ($r = .49$) between winterkilling and fall growth of diallel combinations of 14 alfalfa clones of diverse origin. However, the progenies of one clone, C 318, made substantial fall growth and suffered little winterkilling, suggesting that progress could be made in selection for increased fall growth without sacrificing winterhardiness. Daday and Greenham (1960) showed that winter growth and frost resistance have a low correlation coefficient (r = .15) and they suggested the possibility of combining these characters in one variety. More recently, Larson and Smith (1963) presented evidence of high correlation between winterhardiness and average height, percentages of extra tall and short plants, and the growth habit of plants in variety populations. Varieties with short decumbent plants were more winterhardy than varieties with taller and more upright plants. Crown weight was found to be correlated with the percentage of winter injury. The less hardy varieties tended to have a heavier crown than the more hardy ones.

Seedling Vigor

In small-seeded forages, the ability of the seedling to emerge, to compete with other plants, and to establish itself is often a factor in determining the vigor and density of a stand. Among legumes, birdsfoot trefoil is seriously deficient in this ability. Until the advent of interest in trefoil there had been little need for study of seedling vigor in North American legumes since those in common use were easy to establish. The problem had been more acute in grasses and had led to a number of studies in this group. A review of

North American, British, and Australian literature on this topic may be found in the paper by Kalton et al. (1959). The present literature review on this topic will include papers concerned with legumes whose seed morphology is quite different from that of grasses.

An early study was done by Miller and Pammel (1901) in the greenhouse with 35 legumes (some were agronomic cultivars of the same species). Their observations apparently were visual and made on unreplicated material, but their general conclusion was that in relative size, vigor, and leaf development, the plants from large seeds were superior. They noted the significance of superior leaf development as being related to the fact that the leaf is the site of food production which is converted to tissue in the process of growth. They noticed also that large seeds produced plants with larger root systems.

Cummings (1914) compared large and small seeds of several horticultural crops and found some of the advantages of larger-seeded plants were earlier blossoming, larger blossoms, and a large number of good quality blossoms. Plants from large seed were heavier and bore more and longer lateral branches. He compared the weights and sizes of plants at different stages of growth and concluded that there was a continuous and permanent advantage for the large-seeded plants. He, like Miller and Pammel (1901), observed that plants from large seeds had more leaf area and therefore a larger photosynthetic area. He also measured the embryos of small and large seeds and found that the embryos of large seeds were 13 to 70 percent bigger than those of the small seeds.

A rather extensive review was made of the early literature by Kidd and West (1919) pertaining to the physiological determination of seed condition and its effect on growth and yield. They concluded that plants from larger seeds were more vigorous and produced a better yield. They called attention to the existence of parental differences which, along with the environment, could influence seed size.

Moore (1943) planted 5 seed sizes (extra large, large, medium, small, and extremely small) of crimson clover at 4 depths (0.25, 0.50, 1.5, 2.0 inches). The seed size showing the lowest percentage of emergence was the extra large seed. He explained this only by saying that it may have been due to their abnormally large cotyledons. One may suppose that he meant that they had difficulty in forcing their way through the soil during emergence. Black (1959) reported that in subterranean clover extremely large seeds often failed to produce seedlings due to the fact that one or both cotyledons were broken off the embryo before germination began. He suggested that extra large seeds may receive rougher treatment during mechanical harvesting than smaller seeds.

Erickson (1946) studied three size classes of alfalfa seed in a greenhouse test. His results showed that seedling weight was directly associated with seed size. Also, it was shown that as seed size decreased, emergence decreased. He observed that initial differences in seedling vigor were overcome in 4 months.

The knowledge concerning the influence of seed size on subsequent plant development has been greatly increased by the studies of Black (1955, 1956, 1957a, 1957b, and 1958). Black (1956) studied the influence of seed size on emergence in subterranean clover by sowing seeds of three different sizes at three depths, 0.5, 1.25, and 2.0 inches. He made daily samplings and determined the weights of cotyledon, hypocotyl, and root fractions. From his data, he concluded that one of the effects of seed size was that it determines the depth from which emergence is possible. The evidence indicated that this was not due to the exhaustion of the cotyledonary reserves, but due to limited hypocotyl elongation. A linear relationship existed between seed size and potential hypocotyl elongation. His data indicated another important factor: seed size determines the initial area of the cotyledons since in subterranean clover the seed is composed only of embryo and seed coat. The cotyledonary reserves were of little importance after emergence. He also noted that plants from larger seeds had larger leaves which were held higher than corresponding leaves of plants from small seeds.

Black (1957a) also studied the effects of seed size and strain differences in 4 strains of subterranean clover. His data showed that differences in dry weight at any one time in the early vegetative stages were due to differential seed sizes independent of strain. He pointed out that differences among strains in comparative yield trials could be confounded with seed size, particularly if grown under spaced conditions.

In another study by Black (1957b) on effects of seed size in subterranean clover, the growth rate of plants from three different seed sizes was examined under spaced and sward conditions. Under spaced conditions, the growth rates were maintained in proportion to the initial seed sizes over almost the entire growing season. Under sward conditions, the plots were sown with an equal number of seeds, but different seed sizes were grown in separate plots. In the early part of the growing season, the growth rate was proportional to seed size, but the final yield was the same for all seed sizes. He concluded that the initial growth rates continued until intra-plot competition for light ensued, and this reduction in growth occurred first in the plots sown to large seeds. The plot sown to large seeds were first to reach a stage when all incident light was intercepted; this occurred when the leaf area index reached about 4, that is, when the leaf area is about 4 times that of the ground area. The growth rate of the plots sown to small seeds continued unchanged until this same stage was reached and then decreased.

Continuing this same type of study with subterranean clover, Lawson and Rossiter (1958) sowed plots with large and small seeds in separate plots, but equal weights of viable seed were sown per unit area. The results showed no effects due to seed size provided the embryo weight per unit area was held constant. The growth rate was the same for all plots.

Plots containing an equal number of large and small seeds of subterranean clover were planted by Black (1958) to study what happens to plants in a plot sown with seed of different sizes. He found that over the growing season the number of plants in the mixed plots decreased. The counts taken showed that the number of plants from large seeds remained unchanged, only the plants from small seeds died. The earlier leaf growth of the plants from large seeds developed a canopy above the plants from small seeds causing many of the latter to die out.

Beveridge and Wilsie (1959) studied the influence of depth of planting, seed size, and variety on emergence and seedling vigor in alfalfa. From their results, they concluded that one seed size had no advantage over the other in achieving rapid stand establishment, but within any given depth of planting the large seed produced the most vigorous seedlings. They noted that stands from large seeds would have a higher probability of becoming established under adverse conditions.

Henson and Tayman (1961) studied seedling growth of six strains of birdsfoot trefoil in the greenhouse. Three (Cascade, Tana and Viking) were of the erect European type; the other three were of American origin and prostrate (Empire, Iowa Empire, and North Dakota Empire). The seedlings from large seeds produced more top growth, root growth and produced basal shoots earlier within each strain. Also, the erect strains were superior to the prostrate strains in all of the characters measured.

An attempt was made by Shibles and MacDonald (1962) to determine the cause of the differential growth rate of the erect and prostrate (Viking and Empire) types of birdsfoot trefoil. They used seed of equal sizes of Empire and Viking to eliminate seed size differences. They found that the net photosynthetic rate per unit area of cotyledon was similar for the two varieties. They ascribed the divergence in growth rate in the two varieties to a differential rate of photosynthetic area production. Viking apparently used more of the photosynthate in photosynthetic area production and expansion and less in axis growth than did Empire.

The influence of planting depth, seed size, and variety on emergence and seedling vigor of trefoil was studied by Stickler and Wassom (1963). They planted three seed sizes of three varieties in the greenhouse and in the field at three planting depths. Their results indicated that all of these factors significantly influenced seedling vigor. They concluded that breeding work should be directed toward increasing seed size of birdsfoot trefoil.

Draper and Wilsie (1965) increased the seed size of Viking and Empire trefoil lines by 60 percent and 20 percent, respectively, by three cycles of recurrent selection. These authors did not report what effect this increased seed size had on seedling vigor.

Twamley (1967) investigated the extent to which seed size could be used in a breeding program to screen out lines of poor seedling vigor in the erect or hay-type trefoil. He concluded that no serious loss of superior germplasm would result if 80 percent of the lines were discarded on the basis of seed size. He also found considerable variation in seedling vigor among lines of similar seed size, and he demonstrated that seedling vigor tests of the larger-seeded lines in the greenhouse would help to screen out still further the slow-growing lines. He was unable to explain why some lines with exceptionally large seeds were frequently only average in seedling vigor.

In another experiment, Twamley (1969) used a late-maturing and winterhardy strain, Morshansk, to study the relationship of seedling vigor to seed size, seed load, parental maturity, speed of germination and tillering. The results indicated: (1) that seed load is unlikely to affect greatly the seed size and seedling vigor of the progeny, (2) late-maturing strains with good seedling vigor can be found, (3) 80 percent of the lines in a population of progeny may be discarded on the basis of seed size without serious danger of discarding much germplasm with good seedling vigor, (4) plants arising from large seeds have a pronounced tendency to tiller early, and (5) speed of germination may be of considerable value in detecting lines with good seedling vigor in an unselected population, but it is of limited value for that purpose within the large-seeded fraction of the population.

The Partial Diallel Cross

The diallel cross, which is composed of all possible single crosses among a group of inbred lines, is now a common plan of investigation in plant improvement. Its modern use started with the development of the concepts of general and specific combining ability by Sprague and Tatum (1942). The diallel cross is used to estimate the genetic components of the variation among crosses (see, for instance, Hayman, 1954a, 1954b; Jinks and Hayman, 1953; Griffing, 1956a, 1956b; and Kempthorne, 1956). It is used also to estimate the actual performance of the crosses.

A diallel cross among n inbred lines excluding parents and reciprocals involves a total of $n(n - 1)/2$ crosses. Clearly, this number increases rapidly with n. With limited facilities, this may mean that a complete diallel cross can only be made among a rather small number of lines. Recognizing this problem, Kempthorne and Curnow (1961) proposed a design which allows a large number of inbred lines to be studied by making only a sample of all the possible crosses among them. The three advantages claimed by Kempthorne and Curnow (1961) were:

(1) The variance for general combining ability in the population of which the parents are a sample can be estimated more accurately.

(2) Selection can be made among crosses from a wider range of parents.

(3) The general combining abilities of a larger number of parents can be estimated. Each parent will be assessed with a relatively low precision but larger genetic gains may result from the more intense selection that can be applied to the parents.

G. W. Brown (unpublished, 1948) first suggested sampling the crosses in a circulant manner. Circulant samples have been used twice at Iowa State University (Jensen, 1959; Sprague, unpublished).

Gilbert (1958) proposed that when n is even, the sample should be chosen by superimposing a n x n symmetric Latin square with a single letter on the main diagonal of the table of crosses. Crosses corresponding to a suitable number of letters in the Latin square are then sampled. Each line would be represented in the same number of crosses. Gilbert suggested that when n is divisible by 4, balance should be achieved by using Latin squares symmetrical about both diagonals. He discussed the construction of partial diallels for n = 6 and n = 8 in some detail.

Hinkelmann and Stern (1960) described the construction and analysis of some circulant samples in which line 1 is always crossed with line 2 and with those lines whose numbers form an arithmetic progression from 2 to n. Examples were presented for n = 8, s = 3 and n = 14, s = 5, where n = number of lines and s = number of crosses involving each clone. The emphasis was on the estimation of genetic components of variance.

Kempthorne and Curnow (1961) discussed circulant samples in which n and s were odd and even or even and odd, respectively. Line 1 was crossed with k + 1, k + 2 ..., k + s where $k = \frac{1}{2}(n + 1 - s)$. Line 2 was crossed with lines k + 2, k + 3 ..., k + s + 1 and so on. The existence of circulant samples with n and s both even was mentioned.

Fyfe and Gilbert (1963) proposed "triangular" designs which they claimed are better balanced than Kempthorne and Curnow's (1961) design. These designs are for $N = \frac{1}{2}n(n - 1)$ parents, where n is an integer. The parents are numbered off into an (n - 1)(n - 1) triangle. Clatworthy (1955) also proposed a similar design.

Curnow's (1963) paper dealt mainly with the estimation of general combining ability. He stated that comparisons among the general combining abilities of a set of lines will all have the same variance if and only if a complete diallel cross is made. Consideration was given to partially balanced samples resulting in only two variances for comparing the general combining abilities and to circulant samples that may result in many different variances for the comparisons.

Arunachalam (1967) developed a computer program for analysis of partial diallel crosses based on the model outlined by Kempthorne and Curnow (1961).

MATERIALS AND METHODS

Source and Identification of Materials

Nine clones derived from the variety Empire and nine clones derived from two introductions from Russia were used as parents in this study. Henceforth, they will be referred to as Empire (E) and Russian (R) clones. The 18 parent clones are listed in Table 1.

The Empire clones were obtained from a strain derived by three cycles of selection for large seed size described previously by Draper and Wilsie (1965). This strain traces originally to a commercial seed lot of Empire birdsfoot trefoil obtained in 1960. The nine clones were selected for large seed size and high yields of forage and seed.

The nine Russian clones trace originally to two U.S.S.R. introductions, P.I. 228151 (Kuban) and P.I. 258467 (Morshansk 528). Twenty-eight plant selections from these two accessions were selected for vigor and general agronomic desirability and intercrossed to produce 42 F_1 progenies in 1960. A field nursery of 2400 F_1 plants was established in 1960 and 200 plants were selected from 31 F_1 progenies in 1962 for vigor, flowering, and seed setting. These 200 plants were evaluated for seed size and 18 clones having the largest seed were selected. Open-pollination seed from these 18 clones was used to establish an isolation nursery in 1963. In 1964, 34 plants were selected for vigor, winterhardiness, large seed size and

Table 1. Clones used as parents in partial diallel intra- and intersource crosses

Clone no.	Identification	Clone no.	Identification
1	E 4 - 1	10	R 6 - 8
2	E 4 - 8	11	R 6 - 18
3	E 12 - 1	12	R 9 - 5
4	E 12 - 14	13	R 10 - 6
5	E 15 - 2	14	R 10 - 9
6	E 15 - 15	15	R 10 - 12
7	E 20 - 14	16	R 14 - 5
8	E 20 - 15	17	R 14 - 7
9	E 20 - 21	18	R 22 - 3

good seed production characteristics. Intercross seed produced on the 34 clones in this isolation nursery was combined to form a synthetic, Carroll (formerly designated R-1). In 1966, the nine clones used in this study were selected for seed size, good seed production characteristics and forage yield from a spaced nursery of Carroll and the Syn 1 of the 200 selections.

Greenhouse Procedures

Production of F_1 progenies

In late fall of 1967, the 18 parent clones were dug from the field nursery, replanted in pots, and brought into the greenhouse. They were allowed to grow and develop to the flowering stage for use in crosses.

Partial diallel crosses between and within sources were made in the greenhouse during the winter of 1967-68. Crosses were divided into 3 groups:

Group I: Empire x Empire

Group II: Russian x Russian

Group III: Empire x Russian

Each clone was crossed to 4, 5, or 6 other clones, in such a way that there were 22 cross combinations each in Groups I and II, and 46 in Group III. A total of 90 crosses plus reciprocals were made.

Cross-pollination was effected by hand, using a folded triangular piece of cardboard to remove and transfer pollen from floret to floret. Florets were not emasculated since self-incompatibility prevents self-fertilization almost completely in _L. corniculatus_ (Tome and Johnson, 1945). As possible, crosses and reciprocals were made on the same date. An attempt was made to cross the same number of florets for each cross and its reciprocal. Several umbels of florets on each plant were selfed. Selfing was accomplished by rolling the flower clusters between the thumb and forefinger with a slight pressure. Each umbel was tagged at the time of crossing or selfing.

In four to five weeks, the mature pods were harvested and threshed. The total number of well-filled seeds were counted and divided by the total number of flowers crossed or selfed to determine the cross- and self-fertility indices for each clone.

In April 1968, seeds of reciprocal crosses were bulked, scarified, inoculated, and planted along with four check strains in peat cups arranged in wooden flats in the greenhouse. The checks were Empire, E-1, Russian and Carroll. Empire is the original strain from which E-1 was derived by three cycles of selection for large seed size. Russian was a composite of open-pollination seed from the 18 plants selected for large seed size from the 200 F_1 plants of intercrosses of the two original U.S.S.R. introductions (Kuban and Morshansk 528). The origin of Carroll was given previously. Because of insufficient seedlings in some crosses, only 76 of 90 crosses were used in the experiment. Entry numbers of these crosses and check strains are presented in Table 2.

<u>Production of full-sib progenies</u>

Sixteen F_1 progenies involving four Empire and four Russian clones were selected to study full-sib progenies. The F_1 materials were selected on the basis of general combining ability for forage yield of parent clones in 1968. Four were chosen from Group I, 4 from Group II and 8 from Group III. Pedigrees of the selected F_1 progenies are presented in Table 3.

Stem cuttings were made of six plants picked at random from each of the 16 F_1 progenies. These cuttings were brought into the greenhouse, rooted in vermiculite, transferred to

Table 2. Entry numbers and pedigrees for F_1 progenies and five check strains

Entry no.	Pedigree	Entry no.	Pedigree
1	6 x 13	42	3 x 9
2	7 x 13	43	8 x 15
3	3 x 4	44	3 x 16
4	1 x 14	45	12 x 18
5	13 x 16	46	10 x 15
6	Russian (check)	47	5 x 18
7	6 x 11	48	1 x 8
8	3 x 14	49	11 x 14
9	7 x 14	50	3 x 12
10	5 x 12	51	2 x 8
11	10 x 13	52	2 x 9
12	2 x 3	53	4 x 15
13	4 x 11	54	5 x 11
14	3 x 6	55	8 x 13
15	4 x 10	56	1 x 2
16	11 x 17	57	10 x 17
17	2 x 11	58	10 x 16
18	5 x 8	59	14 x 17
19	8 x 17	60	5 x 6
20	8 x 11	61	5 x 14
21	6 x 7	62	E-1 (check)
22	1 x 7	63	13 x 14
23	9 x 16	64	1 x 16
24	1 x 10	65	17 x 18
25	6 x 15	66	Empire (check)
26	2 x 13	67	4 x 13
27	3 x 10	68	7 x 12
28	7 x 10	69	9 x 14
29	4 x 7	70	1 x 4
30	10 x 11	71	2 x 17
31	8 x 14	72	3 x 18
32	5 x 16	73	Carroll (check)
33	2 x 7	74	13 x 18
34	11 x 18	75	3 x 8
35	2 x 5	76	1 x 18
36	6 x 17	77	7 x 16
37	8 x 9	78	12 x 13
38	E-1 (check)	79	16 x 17
39	12 x 17	80	11 x 16
40	5 x 10	81	4 x 17
41	4 x 5		

Table 3. Selected F_1 progenies used as parents to generate full-sib progenies

Group	Pedigree	Group	Pedigree
I	3 x 6	III	3 x 12
I	3 x 8	III	3 x 18
I	5 x 6	III	5 x 12
I	5 x 8	III	5 x 18
II	12 x 13	III	6 x 13
II	12 x 17	III	6 x 17
II	13 x 18	III	8 x 13
II	17 x 18	III	8 x 17

four-inch pots and allowed to grow and develop to the flowering stage. Because of self-incompatibility in *Lotus corniculatus*, sib-mating was used to obtain second generation seeds. Sib-mating was accomplished according to the method of Lantican (1961) by making cyclic crosses (e.g., 1x2, 2x3, 3x4, ..., 6x1) among the six plants in each progeny. In making the sib-crosses, techniques were the same as those used to produce F_1 seeds.

Mature pods were harvested, threshed and reciprocal crosses bulked. In April 1969, sib-cross seeds were planted along with check strains in peat cups in a way similar to that used for F_1 seeds. Of 96 possible sib-crosses, 92 produced adequate seeds to be included in the field experiment. Entry numbers, corresponding pedigrees of 92 sib-crosses and 8 check entries are shown in Table 4.

Field Procedures

F_1 progenies

During the second week of May, 1968, seedlings of 81 entries (see Table 2) were space planted in a field experiment at the Agronomy and Agricultural Engineering Research Center near Ames. A 9 x 9 triple lattice design with three replicates was used. Each plot consisted of a single row of six plants. Plants were spaced at 24-inch intervals within rows spaced 40 inches apart. In August, 1968, the experiment was overseeded with creeping red fescue to facilitate weed control.

The agronomic characters studied in the F_1 populations are listed in Table 5. Spring vigor, growth habit, and pod set were scored visually on a 1-9 scale with 1 being most vigorous, upright, and good pod set. Yield was recorded in pounds of green forage per plant. Plants alive in the fall but missing the following spring were recorded as winterkilled. Days to bloom were recorded as the number of days from the forage harvest until the first open flower appeared on each plant. Seed size was determined by collecting at random 30 to 35 open-pollinated mature pods per plant. Two plants from each plot were used. Pods were threshed and a 100-seed sample was obtained. Seed size was measured by pouring 100 seeds into a

Table 4. Entry numbers and pedigrees of progenies derived by sib-mating and check strains

Entry no.	Pedigree[a]	Entry no.	Pedigree[a]
1	72-2 x 72-5	41	18-2 x 18-4
2	74-2 x 74-4	42	14-16 x 14-2
3	14-2 x 14-4	43	75-8 x 75-10
4	50-2 x 50-4	44	55-14 x 55-16
5	47-2 x 47-5	45	39-14 x 39-16
6	Russian (check)	46	19-16 x 19-2
7	65-17 x 65-18	47	65-15 x 65-17
8	55-10 x 55-14	48	1-14 x 1-16
9	74-8 x 74-10	49	36-15 x 36-17
10	65-9 x 65-11	50	55-8 x 55-10
11	19-14 x 19-16	51	10-15 x 10-17
12	1-16 x 1-2	52	10-17 x 10-2
13	60-4 x 60-8	53	60-10 x 60-15
14	14-9 x 14-11	54	65-8 x 65-9
15	60-2 x 60-4	55	75-2 x 75-4
16	39-2 x 39-4	56	1-2 x 1-4
17	50-15 x 50-17	57	36-8 x 36-10
18	18-14 x 18-16	58	36-2 x 36-4
19	78-2 x 78-4	59	47-8 x 47-10
20	74-17 x 74-2	60	18-10 x 18-14
21	18-16 x 18-2	61	65-11 x 65-14
22	1-10 x 1-14	62	E-1 (check)
23	Empire (check)	63	39-16 x 39-2
24	47-17 x 47-2	64	50-8 x 50-10
25	72-5 x 72-8	65	47-15 x 47-17
26	50-17 x 50-2	66	Russian (check)
27	55-4 x 55-8	67	60-8 x 60-10
28	72-14 x 72-16	68	72-16 x 72-2
29	18-4 x 18-7	69	78-8 x 78-10
30	19-9 x 19-14	70	1-8 x 1-10
31	75-4 x 75-8	71	55-2 x 55-4
32	65-14 x 65-15	72	55-16 x 55-2
33	10-10 x 10-15	73	E-1 (check)
34	39-4 x 39-8	74	47-5 x 47-8
35	10-8 x 10-10	75	14-14 x 14-16
36	12-8 x 12-10	76	50-10 x 50-15
37	19-4 x 19-7	77	74-15 x 74-17
38	Carroll (check)	78	39-8 x 39-10
39	39-10 x 39-14	79	47-10 x 47-15
40	60-17 x 60-2	80	36-17 x 36-2

[a]First and second numbers refer to entry and plant number of F_1 progeny, respectively.

Table 4. (Continued)

Entry no.	Pedigree[a]	Entry no.	Pedigree[a]
81	60-15 x 60-17	91	78-10 x 78-14
82	78-16 x 78-2	92	75-10 x 75-14
83	17-7 x 17-9	93	72-10 x 72-14
84	75-16 x 75-2	94	74-4 x 74-8
85	36-4 x 36-8	95	78-14 x 78-16
86	Carroll (check)	96	74-10 x 74-15
87	50-4 x 50-8	97	18-7 x 18-10
88	E-1 (check)	98	14-11 x 14-14
89	19-2 x 19-4	99	14-4 x 14-9
90	75-14 x 75-16	100	78-4 x 78-8

1 milliliter pipette and recording the volume in hundredths of a milliliter. When a large number of samples is involved, as in this experiment, volumetric measurement is a rapid method of evaluation compared to weight measurement. A high correlation, r = .93, was found between weight and volume of 100 seeds by Draper and Wilsie (1965).

All data were obtained on individual plants, but the analyses of variance were computed on plot means.

Full-sib progenies

In the spring of 1969, a second field experiment was established at the Research Center by using seedlings of sib-crosses started in the greenhouse. One hundred entries representing 92 sib-crosses and 4 check strains (see Table 4) were arranged in a 10 x 10 triple lattice design with three replicates. Field procedures for this experiment were the same as

Table 5. Agronomic characters determined on individual plants in field experiments

Character	Unit of measure	Date measured or scored	
		F_1 progenies	Full-sib progenies
Yield			
First year	Pounds per plant	July 18, 1968	---
Second year	Pounds per plant	June 16, 1969	June 8, 1970
Growth habit	1 - 9[a]	August 9, 1968	August 6, 1969
Winterkill	Number of plants	May 7, 1969	May 19, 1970
Spring vigor			
Second year	1 - 9[b]	May 7, 1969	May 19, 1970
Third year	1 - 9[b]	May 20, 1970	---
Days to bloom	Days from first cutting	July - August 1969	July - August 1970
Pod set	1 - 9[c]	September 1969	August 20, 1970
Seed size	Milliliters per 100 seeds	November 1969	---

[a] 1 = upright, 9 = prostrate.

[b] 1 = most vigorous, 9 = least vigorous.

[c] 1 = good, 9 = poor.

those described for the F_1 population. Agronomic characters studied in this experiment are listed in Table 5.

Analysis of Field Data

Triple lattice and randomized complete block analyses were conducted on all data. Comparisons between the two designs in both experiments are shown in Table 6. Results indicate that the randomized complete block design was as efficient as the triple lattice arrangement. Similar findings were reported by Wilsie (1954). He suggested that lattice designs are more efficient for testing varieties and strains in broadcast or multiple-row drilled plots than they are for evaluating breeding materials in space-planted single or double-row plots.

Since no advantage was gained by using the triple lattice design, unadjusted treatment means were used in computation in all phases of the analysis. Sums of squares for entries were partitioned into an orthogonal set of comparisons among entries. This involved comparisons among crosses within and between germplasm sources.

General and specific combining ability mean squares for intrasource crosses were obtained by using the method outlined by Kempthorne and Curnow (1961). The AB design of Comstock and Robinson (1952) was used to obtain these estimates for the intersource crosses.

Phenotypic correlations among all characters were calculated in each experiment on an entry mean basis. Correlation

Table 6. Relative efficiency of the triple lattice design compared to a randomized complete block design in testing F_1 and full-sib progenies

Character	Coefficient of variation, %		Rel. efficiency of lattice, %	
	F_1	FS	F_1	FS
Yield, first year	19.7	35.2	102.7	100.0
Yield, second year	37.5	--	100.0	--
Spring vigor, 1969	18.2	--	100.0	--
Spring vigor, 1970	27.6	15.3	101.9	100.0
Winterkill	143.4	130.7	100.3	100.4
Growth habit	20.3	11.6	101.0	101.4
Days to bloom	7.2	11.4	100.0	103.6
Pod set	34.2	15.0	100.4	100.5
Seed size	7.0	--	100.0	--

coefficients were calculated by the formula:

$$r_p = \frac{\Sigma xy}{\sqrt{\Sigma x^2 \Sigma y^2}} ,$$

where Σxy, Σx^2, and Σy^2 were the sum of cross products, sum of squares for x and sum of squares for y, respectively.

Seed Size and Progeny Seedling Vigor Studies

This portion of the experiment was designed to determine the relationship between seed size and progeny seedling vigor traits, and to assess whether improvements had been made in breeding for large seed size.

Seed lots were made by utilizing the seeds used in the seed size study (see Field Procedures). Three-hundred open-pollination seeds from each of 76 F_1 progenies and 5 check entries (E-1 was duplicated) were sown in moist germination towels, enclosed in plastic bags and placed in the germination chamber. Each entry was replicated three times and arranged in a randomized block design. Seven days after sowing, germination counts were made and measurements of radicle and hypocotyl lengths were taken. Two samples consisting of 10 seedlings per sample were measured in each plot. The mean of the two samples from each plot was used as the observation for that plot. All germinated seedlings were oven-dried at 85 degrees centigrade for 24 hours, weighed and dry weights recorded in milligrams per seedling.

Analysis of variance and combining ability analysis were calculated for seed and seedling traits according to the methods outlined under Yield Data Analysis. Phenotypic correlations between seed size and seedling traits were determined by using the formula outlined earlier.

RESULTS

Self- and Cross-fertility of Parent Clones

Self- and cross-fertility of the parent clones used in this study are shown in Tables 7 and 8. In general, the self-fertility of the parent clones was very low. This substantiates previous reports of self-sterility in birdsfoot trefoil. The data also show variation among parent clones in degree of self-sterility. The number of seeds produced per floret selfed ranged from 0 to .785. R6-18 produced the highest number of selfed seeds. Cross-fertility data indicate differences in the ability of the parent clones to set seed when crossed with other clones. R10-9 and R14-7 had the best average performance as male or female parent in both intra- and intersource crosses. These two clones averaged at least one seed per floret crossed. E15-2 produced an average of more than 3 seeds per floret when it was used as the male parent, but it averaged less than a seed per floret when it was the female parent.

F_1 Progenies

General analysis

Mean values for forage yield and other agronomic traits of each F_1 group and check strains are presented in Table 9 and the analysis of variance mean squares for each agronomic trait are shown in Table 10. Analysis and interpretation of seed

Table 7. Self-fertility of parent clones

Clone No.	Clone Name	No. of florets selfed	Pods per floret selfed	Seeds per floret selfed
1	E4-1	121	0	0
2	E4-8	109	0	0
3	E12-1	110	0.009	0.027
4	E12-14	117	0	0
5	E15-2	117	0	0
6	E15-15	104	0	0
7	E20-14	104	0.009	0.077
8	E20-15	110	0	0
9	E20-21	88	0	0
10	R6-8	131	0	0
11	R6-18	135	0.140	0.785
12	R9-5	109	0	0
13	R10-6	97	0.020	0.051
14	R10-9	104	0.009	0.019
15	R10-12	120	0.008	0.025
16	R14-5	122	0	0
17	R14-7	98	0.030	0.133
18	R22-3	113	0.018	0.079

Table 8. Average cross-fertility of parent clones in intrasource and intersource crosses[a]

Clone		Intrasource crosses		Intersource crosses	
No.	Name	As male	As female	As male	As female
1	E4-1	0.68	1.10	0.44	0.74
2	E4-8	0.29	1.42	0.64	0.68
3	E12-1	1.05	0.38	2.84	0.86
4	E12-14	0.04	1.23	0.88	0.51
5	E15-2	3.01	0.64	3.77	0.85
6	E15-15	0.55	0.57	1.48	0.54
7	E20-14	1.66	1.00	1.25	0.55
8	E20-15	1.04	1.53	2.82	0.78
9	E20-21	0.53	0.15	0.43	0.34
10	R6-8	0.42	1.51	0.36	3.95
11	R6-18	1.90	2.41	0.86	1.93
12	R9-5	0.11	0.47	0.01	0.56
13	R10-6	0.48	1.40	0.25	1.80
14	R10-9	2.57	1.05	1.97	1.98
15	R10-12	0.05	0.14	0.01	0.43
16	R14-5	0.75	0.47	0.20	1.46
17	R14-7	1.72	1.69	1.31	2.70
18	R22-3	1.50	0.10	0.87	0.65

[a]Number of seeds obtained divided by number of flowers crossed.

Table 9. Mean values for agronomic characters of each F_1 group and check strains

Group	Material	Yield (lb/plant) 1968	Yield (lb/plant) 1969	Spring 1969
I	Empire (E) F_1's	0.28 ± .01	1.04 ± 0.08	6.9 ± 0.2
II	Russian (R) F_1's	0.36 ± .01	1.78 ± 0.09	5.5 ± 0.2
III	E x R F_1's	0.36 ± .01	1.63 ± 0.06	6.0 ± 0.1
Checks				
	Empire	0.31 ± .09	1.85 ± 0.78	6.4 ± 1.6
	E-1	0.27 ± .04	1.51 ± 0.33	6.8 ± 0.7
	Russian	0.26 ± .09	2.31 ± 0.78	4.3 ± 1.6
	Carroll	0.36 ± .09	1.80 ± 0.78	5.4 ± 1.6
Mean of checks		0.30 ± .02	1.86 ± 0.17	5.7 ± 0.3

[a]Scored 1-9; 1 = most vigorous, 9 = least vigorous.

[b]Scored 1-9; 1 = upright, 9 = prostrate.

[c]Scored 1-9; 1 = good, 9 = poor.

vigor score[a] 1970	Plants winterkilled 1969	Growth habit score[b] 1968	Days to bloom 1969	Pod set score[c] 1969
6.2 ± 0.2	0.9 ± 0.1	5.6 ± 0.2	34.3 ± 0.3	2.7 ± 0.1
4.9 ± 0.2	0.3 ± 0.1	6.2 ± 0.2	34.1 ± 0.3	1.8 ± 0.1
5.6 ± 0.1	0.6 ± 0.1	5.7 ± 0.1	33.9 ± 0.2	2.2 ± 0.1
5.6 ± 2.2	0.3 ± 1.2	8.5 ± 1.7	39.5 ± 3.5	2.4 ± 1.1
7.6 ± 0.9	0.5 ± 0.5	9.0 ± 0.8	38.9 ± 1.5	2.2 ± 0.5
3.9 ± 2.2	0.0 ± 1.2	6.0 ± 1.7	33.4 ± 3.5	1.3 ± 1.1
5.3 ± 2.2	0.0 ± 1.2	6.2 ± 1.7	34.3 ± 3.5	2.4 ± 1.1
5.6 ± 0.5	0.2 ± 0.3	7.4 ± 0.4	36.4 ± 0.8	2.0 ± 0.2

Table 10. Analyses of variance for agronomic characters in tests of F_1 progenies

Source of variation	df	Mean squares: Forage yield 1968	Forage yield 1969	Spring vigor 1969	Spring vigor 1970	Plants winter-killed 1969	Growth habit 1968	Days to bloom 1969	Pod set 1969
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Replications	2	0.003	0.312	2.975	2.730	0.868	38.60**	15.94*	7.524**
Entries	80	0.023**	1.282**	4.051**	7.881**	1.985**	14.76**	27.26**	1.144**
Empire (E) F_1's[a]	18	0.019**	1.012**	4.002**	11.155**	4.232**	19.20**	37.99**	0.796
Russian (R) F_1's[b]	17	0.017**	0.561*	2.751**	6.103**	0.571	10.30**	7.58	1.515*
E x R F_1's[c]	38	0.023**	1.393**	3.606**	6.580**	1.575**	14.89**	31.06**	1.019**
Check strains	4	0.007	0.044	3.646*	8.123*	0.057	6.86**	23.33**	0.886
Checks vs others	1	0.038**	1.908*	0.405	2.122	1.656	55.07**	86.67**	0.724
(E,R) vs (E x R)	1	0.049**	4.124**	7.558*	0.506	1.217	4.81	7.42	1.511
E vs R	1	0.194**	14.016**	45.678**	40.725**	8.084**	6.39**	0.57	1[illegible].812**
Error	160	0.005	0.297	1.235	2.456	0.714	1.45	6.07	0.568
C.V. (%)		(19.7)	(37.5)	(18.2)	(27.6)	(143.4)	(20.3)	(7.2)	(34.2)

[a] S.E. for 1,2,3,4,5,6,7,8 are .006, .320, 1.266, 3.527, 1.410, 5.92, 12.01, .252, respectively.

[b] S.E. for 1,2,3,4,5,6,7,8 are .005, .182, .892, 1.979, .185, 3.34, 2.45, .492, respectively.

[c] S.E. for 1,2,3,4,5,6,7,8 are .005, .311, .806, 1.471, .352, 3.32, 6.94, .228, respectively.

*Significant at the .05 level of probability.

**Significant at the .01 level of probability.

size data is included in the section on progeny seedling vigor studies. Highly significant differences among entries were observed for all agronomic characters studied.

Differences in the magnitude of the mean square for crosses in each hybrid group indicated differences among groups in genetic variability. The largest mean square for forage yield was found among crosses between germplasm sources. Crosses among Empire clones had the largest mean square for spring vigor, winterhardiness, growth habit, and days to bloom. The largest mean square for pod production was obtained among Russian x Russian crosses. Differences among crosses for pod set within the Empire x Empire group and for winterhardiness and days to bloom within the Russian x Russian group were not significant.

Analysis of variance showed that the four checks differed significantly for growth habit, days to bloom, and spring vigor, but not for forage yield, winterhardiness and seed set. Russian was the most upright in growth habit, the earliest maturing and the most vigorous check strain; whereas, E-1 was the least vigorous and most decumbent in growth habit.

Orthogonal comparisons indicated that crosses as a group yielded significantly (.01 level) more than the checks, as a group, in the first year, but the reverse was true in the second year. Hybrids also tended to be more upright and earlier maturing than the checks, as a group.

When considered as groups, crosses between sources gave yields higher than those within sources. The intersource crosses gave a yield increase of 12 and 16 percent in 1968 and 1969, respectively, over the intrasource crosses, or an average of 14 percent heterosis for the two-year period (Table 11). For spring vigor, intersource crosses were significantly superior to the intrasource crosses in the first year (1969), but this superiority was not manifested the following year. No significant differences were found for other traits when crosses within sources were compared with those between sources.

Table 11. Extent of heterosis (intersource average less intrasource average) for forage yield in intersource crosses

	Forage yield (lb/plot)			
Year	Intersource crosses	Intrasource crosses	Heterosis	% heterosis
1968	0.36	0.32	0.04	12
1969	1.63	1.41	0.22	16
Mean	1.00	0.86	0.13	14

Comparisons between Empire and Russian crosses revealed the superiority of Russian x Russian over Empire x Empire crosses in yield, vigor, winterhardiness and pod production. For growth habit, Empire x Empire crosses appeared to be more upright than Russian x Russian crosses. The two groups did not differ significantly in days to bloom.

Combining ability studies

General and specific combining ability mean squares for each agronomic trait studied in the three hybrid groups are shown in Tables 12, 13 and 14. Highly significant mean squares for general combining ability were obtained for most traits in the three groups. Specific combining ability mean squares for first year yield, winterhardiness and spring vigor were significant in the Empire x Empire group. In the Russian x Russian crosses, second year yield was the only trait with a significant specific combining ability mean square. None of the specific combining ability mean squares were significant in the Empire x Russian group. General combining ability mean squares were much larger than specific combining ability mean squares for practically all traits.

The average agronomic performance of each parent clone in crosses within and between sources is presented together with means for check strains in Tables 15 and 16. In intra-source crosses, clones giving the highest total yields, in order of magnitude, were R10-12 and R9-5. Those having the lowest total yields were E4-8 and E20-21. Those same clones highest in forage yield were also the most outstanding in spring vigor and winterhardiness. For pod production, R10-12, R14-5 and R6-8 were the most productive, with E15-2 and E20-21 being the least productive. E20-21 and E20-15 were the most

Table 12. General and specific combining ability mean squares for agronomic characters in Empire x Empire F_1 progenies

Character	Mean squares GCA (8 df)	SCA (10 df)	Error (160 df)
Yield, 1968	0.023**	0.016**	0.005
Yield, 1969	1.82**	0.37	0.297
Spring vigor, 1969	5.62**	2.70*	1.24
Spring vigor, 1970	17.27**	6.26**	2.45
Winterhardiness	5.61**	3.13**	0.71
Growth habit	41.58**	1.31	1.45
Days to bloom	78.76**	5.38	6.07
Pod set	1.11*	0.55	0.57

*Significant at the .05 level of probability.

**Significant at the .01 level of probability.

Table 13. General and specific combining ability mean squares for agronomic characters in Russian x Russian F_1 progenies

Character	Mean squares GCA (8 df)	SCA (9 df)	Error (160 df)
Yield, 1968	0.031**	0.005	0.005
Yield, 1969	0.443	0.666*	0.297
Spring vigor, 1969	4.27**	1.40	1.24
Spring vigor, 1970	9.54**	3.05	2.45
Winterhardiness	0.818	0.351	0.71
Growth habit	19.83**	1.83	1.45
Days to bloom	2.98*	2.78	6.07
Pod set	1.39*	0.93	0.57

*Significant at the .05 level of probability.

**Significant at the .01 level of probability.

Table 14. General and specific combining ability mean squares for agronomic characters in Empire x Russian F_1 progenies

Character	Mean squares: GCA, Empire (8 df)	GCA, Russian (8 df)	SCA, E x R (22 df)	Error (160 df)
Yield, 1968	0.063**	0.028**	0.004	0.005
Yield, 1969	4.35**	1.08**	0.26	0.297
Spring vigor, 1969	8.14**	4.34**	1.01	1.24
Spring vigor, 1970	16.64*	3.55	2.94	2.45
Winterhardiness	4.37**	1.32	0.71	0.71
Growth habit	46.42**	7.86**	1.91	1.45
Days to bloom	86.28**	22.55**	5.54	6.07
Pod set	1.92**	0.95	0.53	0.57

*Significant at the .05 level of probability.

**Significant at the .01 level of probability.

upright in growth habit and R6-18 and R22-3 were the most prostrate. The two most upright clones were also the earliest in maturity and E12-14 was the latest.

In intersource crosses, E15-15 was the best forage-yielding clone, followed by R9-5, E12-14 and E12-1. Lowest yielders were E20-21 and E20-15. The highest yielding clone, E15-15, was also the most outstanding in vigor and winterhardiness. E20-14, E12-14, R10-9, E15-15 and E4-1 produced the most pods and E15-2 produced the fewest. For growth habit, R9-5 and E20-14 were the most upright and E4-8 was the most decumbent. For flowering date, E20-14, E20-15 and E20-21 were the earliest and R22-3 was the latest.

Agronomic performance of individual F_1 progenies in the three groups and check strains is presented in Tables 17, 18,

Table 15. Average performance of Empire and Russian clones in intrasource crosses together with means for check strains

Clone No.	Clone Name	Yield (lb/plant) 1968	Yield (lb/plant) 1969	Spring vigor score[a] 1969	Spring vigor score[a] 1970	Plants winter-killed 1969	Growth habit score[b] 1968	Days to bloom 1969	Pod set score[c] 1969
1	E4-1	0.26	0.82	7.1	6.8	0.4	6.3	36.0	2.4
2	E4-8	0.25	0.67	7.8	7.7	1.3	7.2	34.6	2.6
3	E12-1	0.35	1.59	6.0	4.4	0.1	5.1	35.4	2.3
4	E12-14	0.28	1.29	6.7	6.2	0.5	7.5	38.1	2.7
5	E15-2	0.28	1.05	7.0	6.4	1.0	6.7	35.6	3.2
6	E15-15	0.30	1.64	5.7	4.2	0.3	6.7	35.6	2.8
7	E20-14	0.26	0.83	6.8	6.5	1.0	5.4	32.7	2.7
8	E20-15	0.33	0.95	7.2	6.4	1.6	3.1	31.0	2.7
9	E20-21	0.25	0.60	7.7	6.9	2.1	2.8	30.1	3.0
10	R6-8	0.32	1.56	5.9	6.2	0.6	5.5	33.7	1.6
11	R6-18	0.34	1.70	5.8	5.2	0.5	7.7	33.2	1.9
12	R9-5	0.46	1.93	5.2	3.5	0.0	4.9	35.2	2.1
13	R10-6	0.34	1.80	5.4	5.2	0.4	6.5	33.4	1.8
14	R10-9	0.34	1.56	6.5	6.0	0.7	7.2	33.0	2.1
15	R10-12	0.32	2.21	4.4	4.0	0.0	6.4	33.1	1.0
16	R14-5	0.33	1.89	5.1	5.0	0.4	5.4	34.8	1.5
17	R14-7	0.42	1.65	5.8	4.7	0.3	4.7	34.9	2.5
18	R22-3	0.44	1.78	6.0	4.2	0.2	7.7	35.6	2.5
Check strains									
	Empire	0.31	1.85	6.4	5.6	0.3	8.5	39.5	2.4
	E-1	0.27	1.51	6.8	7.6	0.5	9.0	38.9	2.2
	Russian	0.26	2.31	4.3	3.9	0.0	6.0	33.4	1.3
	Carroll	0.36	1.80	5.4	5.3	0.0	6.2	34.3	2.4
Mean of checks		0.30	1.86	5.7	5.6	0.2	7.4	36.4	2.0

[a]Scored 1-9; 1 = most vigorous, 9 = least vigorous.

[b]Scored 1-9; 1 = upright, 9 = prostrate.

[c]Scored 1-9; 1 = good, 9 = poor.

Table 16. Average performance of Empire and Russian clones in intersource crosses together with means for check strains

Clone No.	Clone Name	Yield (lb/plant) 1968	Yield (lb/plant) 1969	Spring vigor score[a] 1969	Spring vigor score[a] 1970	Plants winter-killed 1969	Growth habit score[b] 1968	Days to bloom 1969	Pod set score[c] 1969
1	E4-1	0.34	1.65	6.0	5.1	0.2	7.6	36.8	1.9
2	E4-8	0.33	1.48	6.8	6.3	0.6	8.3	34.7	2.0
3	E12-1	0.43	2.02	5.5	4.8	0.2	4.9	35.8	2.3
4	E12-14	0.41	2.04	5.7	4.6	0.1	7.3	35.9	1.8
5	E15-2	0.43	1.74	6.0	5.9	0.9	5.6	34.6	2.9
6	E15-15	0.41	2.56	5.1	3.5	0.0	7.8	36.2	1.9
7	E20-14	0.28	1.42	4.8	5.9	0.2	2.8	29.6	1.7
8	E20-15	0.29	0.74	7.0	7.1	1.2	3.0	30.2	2.1
9	E20-21	0.21	0.70	7.9	8.0	2.0	4.9	30.3	2.8
10	R6-8	0.34	1.84	6.0	5.6	0.7	5.6	34.7	2.2
11	R6-18	0.32	1.65	6.7	5.9	0.7	7.7	33.1	2.1
12	R9-5	0.45	2.25	4.6	5.3	0.4	2.8	32.1	2.1
13	R10-6	0.34	1.71	5.3	5.1	0.1	5.8	32.4	2.0
14	R10-9	0.33	1.34	6.0	6.7	0.5	4.9	31.9	1.8
15	R10-12	0.36	1.99	5.5	3.9	0.2	6.2	33.8	2.0
16	R14-5	0.33	1.62	5.8	5.2	0.5	5.5	33.8	2.7
17	R14-7	0.44	1.42	6.7	5.6	1.0	5.4	35.0	2.0
18	R22-3	0.40	1.25	6.6	5.8	0.4	6.5	39.3	2.7
Check strains									
	Empire	0.31	1.85	6.4	5.6	0.3	8.5	39.5	2.4
	E-1	0.27	1.51	6.8	7.6	0.5	9.0	38.9	2.2
	Russian	0.26	2.31	4.3	3.9	0.0	6.0	33.4	1.3
	Carroll	0.36	1.80	5.4	5.3	0.0	6.2	34.3	2.4
Mean of checks		0.30	1.86	5.7	5.6	0.2	7.4	36.4	2.0

[a]Scored 1-9; 1 = most vigorous, 9 = least vigorous.

[b]Scored 1-9; 1 = upright, 9 = prostrate.

[c]Scored 1-9; 1 = good, 9 = poor.

Table 17. Mean performance of individual F_1 progenies of Empire x Empire crosses

Clone	Cross	Yield (lb/plant) 1968	Yield (lb/plant) 1969	Spring vigor score[a] 1969	Spring vigor score[a] 1970	Plants winter-killed 1969	Growth habit score[b] 1968	Days to bloom 1969	Pod set score[c] 1969
E4-1	1x2	0.18	0.43	7.8	8.5	0.7	8.9	36.8	2.2
	1x4	0.19	1.08	7.2	7.4	0.3	8.5	41.9	2.7
	1x7	0.27	0.70	6.6	6.0	0.0	4.1	32.2	2.3
	1x8	0.42	1.08	6.8	5.4	0.7	3.8	33.4	2.2
	Mean	0.26	0.82	7.1	6.8	0.4	6.3	36.0	2.4
E4-8	2x1	0.18	0.43	7.8	8.5	0.7	8.9	36.3	2.2
	2x3	0.34	1.08	7.0	6.6	0.0	8.0	36.9	1.8
	2x5	0.28	0.60	8.7	8.7	2.3	7.6	37.8	3.7
	2x7	0.17	0.45	8.2	8.5	2.3	6.3	33.3	2.5
	2x8	0.29	0.97	7.4	6.7	1.3	6.0	31.9	2.2
	2x9	0.25	0.48	7.7	7.4	1.3	6.3	31.7	3.2
	Mean	0.25	0.67	7.8	7.7	1.3	7.2	34.6	2.6
E12-1	3x2	0.34	1.08	7.0	6.6	0.0	8.0	36.9	1.8
	3x4	0.28	2.30	5.9	5.1	0.0	8.0	38.6	2.0
	3x6	0.43	1.71	5.9	3.4	0.3	5.9	39.3	2.4
	3x8	0.39	1.64	5.4	3.2	0.0	2.2	31.0	2.9
	3x9	0.31	1.24	6.0	3.5	0.3	1.2	31.3	2.4
	Mean	0.35	1.59	6.0	4.4	0.1	5.1	35.4	2.3

[a] Scored 1-9; 1 = most vigorous, 9 = least vigorous.

[b] Scored 1-9; 1 = upright, 9 = prostrate.

[c] Scored 1-9; 1 = good, 9 = poor.

Table 17. (Continued)

Clone	Cross	Yield (lb/plant) 1968	Yield (lb/plant) 1969	Spring vigor score[a] 1969	Spring vigor score[a] 1970	Plants winter-killed 1969	Growth habit score[b] 1968	Days to bloom 1969	Pod set score[c] 1969
E12-14	4x1	0.19	1.08	7.2	7.4	0.3	8.5	41.9	2.7
	4x3	0.28	2.30	5.9	5.1	0.0	8.0	38.6	2.0
	4x5	0.32	1.15	6.1	5.0	0.0	8.0	37.4	2.9
	4x7	0.31	0.64	7.6	7.3	1.7	5.5	34.5	3.2
	Mean	0.28	1.29	6.7	6.2	0.5	7.5	38.1	2.7
E15-2	5x2	0.28	0.60	8.7	8.7	2.3	7.6	37.8	3.7
	5x4	0.32	1.15	6.1	5.0	0.0	8.0	37.4	2.9
	5x6	0.19	1.63	6.3	5.0	0.7	8.5	36.5	3.2
	5x8	0.37	0.87	7.1	6.9	1.3	2.7	32.0	2.8
	Mean	0.28	1.05	7.0	6.4	1.0	6.7	35.6	3.2
E15-15	6x3	0.43	1.71	5.9	3.4	0.3	5.9	39.3	2.4
	6x5	0.19	1.63	6.3	5.0	0.7	8.5	36.5	3.2
	6x7	0.27	1.58	4.9	4.2	0.0	5.7	32.0	2.7
	Mean	0.30	1.64	5.7	4.2	0.3	6.7	35.6	2.8
E20-14	7x1	0.27	0.70	6.6	6.0	0.0	4.2	32.2	2.3
	7x2	0.17	0.45	8.2	8.5	2.3	6.3	33.3	2.5
	7x4	0.31	0.64	7.6	7.3	1.7	5.5	34.5	3.2
	7x6	0.27	1.58	4.9	4.2	0.0	5.7	32.0	2.7
	Mean	0.26	0.83	6.8	6.5	1.0	5.4	32.7	2.7

Table 17. (Continued)

Clone	Cross	Yield (lb/plant) 1968	Yield (lb/plant) 1969	Spring vigor score[a] 1969	Spring vigor score[a] 1970	Plants winter-killed 1969	Growth habit score[b] 1968	Days to bloom 1969	Pod set score[c] 1969
E20-15	8x1	0.42	1.08	6.8	5.4	0.7	3.8	33.4	2.2
	8x2	0.29	0.97	7.4	6.7	1.3	6.0	31.9	2.2
	8x3	0.39	1.64	5.4	3.2	0.0	2.2	31.0	2.9
	8x5	0.37	0.87	7.1	6.9	1.3	2.7	32.0	2.8
	Mean	0.33	0.95	7.2	6.4	1.6	3.1	31.0	2.7
E20-21	9x2	0.25	0.48	7.7	7.4	1.3	6.3	31.7	3.2
	9x3	0.31	1.24	6.0	3.5	0.3	1.2	31.3	2.4
	9x8	0.20	0.09	9.5	9.7	4.7	1.0	28.0	3.5
	Mean	0.25	0.60	7.7	6.9	2.1	2.8	30.1	3.0
Check strains									
Empire		0.31	1.85	6.4	5.6	0.3	8.5	39.5	2.4
E-1		0.27	1.51	6.8	7.6	0.5	9.0	38.3	2.0
Russian		0.26	2.31	4.3	3.9	0.0	6.0	33.4	1.3
Carroll		0.36	1.80	5.4	5.3	0.0	6.2	34.3	2.4
Mean of checks		0.30	1.86	5.7	5.6	0.2	7.4	36.4	2.0
L.S.D. (.05)		0.11	0.89	1.8	2.5	1.4	2.0	4.0	1.2

Table 18. Mean performance of individual F_1 progenies of Russian x Russian crosses

Clone	Cross	Yield (lb/plant) 1968	Yield (lb/plant) 1969	Spring vigor score[a] 1969	Spring vigor score[a] 1970	Plants winter-killed 1969	Growth habit score[b] 1968	Days to bloom 1969	Pod set score[c] 1969
R6-8	10x11	0.29	1.30	6.3	7.2	1.0	7.2	33.7	2.8
	10x13	0.35	1.40	6.6	7.4	1.3	6.2	32.9	1.0
	10x15	0.32	2.21	4.4	4.0	0.0	6.4	33.1	1.0
	10x16	0.25	1.35	6.4	7.2	0.7	4.9	34.6	1.3
	10x17	0.40	1.58	6.0	5.1	0.7	2.7	34.3	2.2
	Mean	0.32	1.56	5.9	6.2	0.6	5.5	33.7	1.6
R6-18	11x10	0.29	1.30	6.3	7.2	1.0	7.2	33.7	2.8
	11x14	0.31	1.70	6.0	4.9	0.7	8.0	31.8	1.7
	11x16	0.33	1.98	5.1	5.2	0.0	7.4	34.9	1.6
	11x17	0.37	1.48	5.2	4.4	0.0	7.1	32.6	1.9
	11x18	0.38	2.14	6.2	4.4	0.7	8.9	33.9	1.7
	Mean	0.34	1.70	5.8	5.2	0.5	7.7	33.2	1.9
R9-5	12x13	0.37	2.09	3.8	3.0	0.0	4.3	34.3	1.9
	12x17	0.48	1.93	5.8	4.3	0.0	3.1	34.7	1.9
	12x18	0.54	1.82	5.9	3.0	0.0	7.3	36.8	2.6
	Mean	0.46	1.93	5.2	3.5	0.0	4.9	35.2	2.1

[a]Scored 1-9; 1 = most vigorous, 9 = least vigorous.

[b]Scored 1-9; 1 = upright, 9 = prostrate.

[c]Scored 1-9; 1 = good, 9 = poor.

Table 18. (Continued)

Clone	Cross	Yield (lb/plant) 1968	Yield (lb/plant) 1969	Spring vigor score[a] 1969	Spring vigor score[a] 1970	Plants winter-killed 1969	Growth habit score[b] 1968	Days to bloom 1969	Pod set score[c] 1969
R10-6	13x10	0.35	1.40	6.6	7.4	1.3	6.2	32.9	1.0
	13x12	0.37	2.09	3.8	3.0	0.0	4.3	34.3	1.9
	13x14	0.31	1.12	7.2	7.3	1.0	7.7	33.0	2.0
	13x16	0.33	2.22	3.6	3.7	0.0	5.8	33.3	1.3
	13x18	0.35	2.17	5.6	4.6	0.0	8.7	35.4	2.9
	Mean	0.34	1.80	5.4	5.2	0.4	6.5	33.4	1.8
R10-9	14x11	0.31	1.70	6.0	4.9	0.7	8.0	31.8	1.7
	14x13	0.31	1.12	7.2	7.3	1.0	7.7	33.0	2.0
	14x17	0.42	1.90	6.3	5.7	0.3	6.0	35.4	2.7
	Mean	0.34	1.56	6.5	6.0	0.7	7.2	33.0	2.1
R10-12	15x10	0.32	2.21	4.4	4.0	0.0	6.4	33.1	1.0
	Mean	0.32	2.21	4.4	4.0	0.0	6.4	33.1	1.0
R14-5	16x10	0.25	1.35	6.4	7.2	0.7	4.9	34.6	1.3
	16x11	0.33	1.98	5.1	5.2	0.0	7.4	34.9	1.6
	16x13	0.33	2.22	3.6	3.7	0.0	5.8	33.3	1.3
	16x17	0.42	2.04	5.3	3.9	0.7	3.2	36.5	1.8
	Mean	0.33	1.89	5.1	5.0	0.4	5.4	34.8	1.5

Table 18. (Continued)

Clone	Cross	Yield (lb/plant) 1968	Yield (lb/plant) 1969	Spring vigor score[a] 1969	Spring vigor score[a] 1970	Plants winter-killed 1969	Growth habit score[b] 1968	Days to bloom 1969	Pod set score[c] 1969
R14-7	17x10	0.40	1.58	6.0	5.1	0.7	2.7	34.3	2.2
	17x11	0.37	1.48	5.2	4.4	0.0	7.1	32.6	1.9
	17x12	0.48	1.93	5.8	4.3	0.0	3.1	34.7	1.9
	17x14	0.42	1.90	6.3	5.7	0.3	6.0	35.4	2.7
	17x16	0.42	2.04	5.3	3.9	0.7	3.4	36.5	1.8
	17x18	0.49	1.08	6.4	4.9	0.3	5.8	37.9	2.9
	Mean	0.42	1.65	5.8	4.7	0.3	4.7	34.9	2.2
R22-3	18x11	0.38	2.14	6.2	4.4	0.7	8.9	33.9	1.7
	18x12	0.54	1.82	5.9	3.0	0.0	7.3	36.8	2.6
	18x13	0.35	2.17	5.6	4.6	0.0	8.7	35.4	2.9
	18x17	0.49	1.08	6.4	4.9	0.3	5.8	37.9	2.9
	Mean	0.44	1.78	6.0	4.2	0.2	7.7	35.6	2.5
Check strains									
Russian		0.26	2.31	4.3	3.9	0.0	6.0	33.4	1.3
Carroll		0.36	1.80	5.4	5.3	0.0	6.2	34.3	2.4
Empire		0.31	1.85	6.4	5.6	0.3	8.5	39.5	2.4
E-1		0.27	1.51	6.8	7.6	0.5	9.0	38.2	2.0
Mean of checks		0.30	1.86	5.7	5.6	0.2	7.4	36.4	2.0
L.S.D. (.05)		0.11	0.89	1.8	2.5	1.4	2.0	4.0	1.2

Table 19. Mean performance of individual F_1 progenies of Empire x Russian crosses

Clone	Cross	Yield (lb/plant) 1968	Yield (lb/plant) 1969	Spring vigor score[a] 1969	Spring vigor score[a] 1970	Plants winter-killed 1969	Growth habit score[b] 1968	Days to bloom 1969	Pod set score[c] 1969
E4-1	1x10	0.28	2.11	5.6	4.3	0.0	7.7	36.3	1.7
	1x14	0.37	2.07	6.0	5.8	0.3	7.8	35.5	1.1
	1x16	0.37	1.50	5.7	4.9	0.0	8.1	36.8	2.7
	1x18	0.34	0.99	6.9	5.4	0.3	6.8	40.1	2.3
	Mean	0.34	1.65	6.0	5.1	0.2	7.6	36.8	1.9
E4-8	2x11	0.33	1.36	7.3	6.8	0.7	8.4	34.0	2.3
	2x13	0.30	1.63	5.7	5.7	0.0	8.4	34.7	2.2
	2x17	0.35	1.47	7.4	6.4	1.3	8.2	35.5	1.4
	Mean	0.33	1.48	6.8	6.3	0.6	8.3	34.7	2.0
E12-1	3x10	0.39	1.66	6.6	5.9	1.0	5.6	34.5	2.4
	3x12	0.48	2.57	4.8	4.0	0.0	3.4	35.7	2.2
	3x14	0.41	1.86	5.4	6.0	0.0	5.2	34.0	2.0
	3x16	0.47	2.56	4.6	2.9	0.0	4.1	36.8	2.8
	3x18	0.40	1.55	6.2	5.2	0.0	6.3	39.3	2.2
	Mean	0.43	2.02	5.5	4.8	0.2	4.9	36.1	2.3

[a]Scored 1-9; 1 = most vigorous, 9 = least vigorous.

[b]Scored 1-9; 1 = upright, 9 = prostrate.

[c]Scored 1-9; 1 = good, 9 = poor.

Table 19. (Continued)

Clone	Cross	Yield (lb/plant) 1968	Yield (lb/plant) 1969	Spring vigor score[a] 1969	Spring vigor score[a] 1970	Plants winter-killed 1969	Growth habit score[b] 1968	Days to bloom 1969	Pod set score[c] 1969
E12-14	4x10	0.38	2.34	5.6	4.8	0.0	7.1	39.0	1.5
	4x11	0.32	2.20	6.1	5.2	0.7	8.2	36.1	1.9
	4x13	0.42	1.96	5.8	4.7	0.0	7.9	33.0	1.3
	4x15	0.40	1.88	5.8	4.4	0.0	7.0	35.8	2.2
	4x17	0.52	1.94	5.3	3.8	0.0	6.6	37.4	1.9
	Mean	0.41	2.04	5.7	4.6	0.1	7.3	35.9	1.8
E15-2	5x10	0.43	1.98	6.4	7.0	1.7	5.0	34.4	3.4
	5x11	0.41	1.41	7.0	5.9	1.3	7.7	31.7	2.2
	5x12	0.46	2.51	4.7	4.8	1.3	3.0	33.4	2.4
	5x14	0.38	1.58	5.7	5.9	0.3	5.3	35.6	2.8
	5x16	0.41	1.79	5.6	4.9	0.0	6.0	34.5	3.0
	5x18	0.47	1.24	6.7	6.7	1.0	6.4	39.8	3.5
	Mean	0.43	1.74	6.0	5.9	0.9	5.6	34.6	2.9
E15-15	6x11	0.33	2.60	5.9	5.0	0.0	9.0	35.6	2.0
	6x13	0.38	2.90	4.3	2.2	0.0	8.1	35.8	1.7
	6x15	0.40	2.97	4.7	2.7	0.0	8.2	36.2	1.9
	6x17	0.50	1.87	5.6	4.0	0.0	6.0	37.0	2.0
	Mean	0.41	2.56	5.1	3.5	0.0	7.8	36.2	1.9
E20-14	7x10	0.20	1.17	6.0	6.2	1.0	2.7	30.9	2.1
	7x12	0.41	1.75	4.3	7.0	0.0	2.1	28.2	1.8
	7x13	0.27	1.62	3.8	5.2	0.0	2.2	30.6	2.0
	7x14	0.30	1.27	4.7	6.3	0.0	3.1	28.4	1.4
	7x16	0.18	1.34	5.1	5.0	0.0	3.2	31.5	1.4
	Mean	0.28	1.42	4.8	5.9	0.2	2.8	29.6	1.7

Table 19. (Continued)

Clone	Cross	Yield (lb/plant) 1968	Yield (lb/plant) 1969	Spring vigor score[a] 1969	Spring vigor score[a] 1970	Plants winter-killed 1969	Growth habit score[b] 1968	Days to bloom 1969	Pod set score[c] 1969
E20-15	8x11	0.20	0.74	7.3	6.7	1.0	5.0	30.0	2.0
	8x13	0.29	0.51	6.9	7.6	0.7	2.2	29.8	2.9
	8x14	0.27	0.86	6.6	8.2	1.0	3.3	29.6	1.5
	8x15	0.30	1.17	5.9	4.7	0.7	3.4	30.2	1.8
	8x17	0.39	0.45	8.6	8.2	2.7	1.1	31.6	2.6
	Mean	0.29	0.74	7.0	7.1	1.2	3.0	30.2	2.1
E20-21	9x14	0.22	0.45	7.8	7.8	1.3	4.7	30.0	2.3
	9x16	0.20	0.95	8.0	8.3	2.7	5.0	30.7	3.4
	Mean	0.21	0.70	7.9	8.0	2.0	4.9	30.3	2.8
R6-8	10x1	0.28	2.11	5.6	4.3	0.0	7.7	36.3	1.7
	10x3	0.39	1.66	6.6	5.9	1.0	5.6	34.5	2.4
	10x4	0.38	2.34	5.6	4.8	0.0	7.1	39.0	1.5
	10x5	0.43	1.98	6.4	7.0	1.7	5.0	34.4	3.4
	10x7	0.20	1.17	6.0	6.2	1.0	2.7	30.9	2.1
	Mean	0.34	1.84	6.0	5.6	0.7	5.6	34.7	2.2
R6-18	11x2	0.33	1.36	7.3	6.8	0.7	8.4	34.0	2.3
	11x4	0.32	2.20	6.1	5.2	0.7	8.2	36.1	1.9
	11x5	0.41	1.41	7.0	5.9	1.3	7.7	31.7	2.2
	11x6	0.33	2.60	5.9	5.0	0.0	9.0	35.6	2.0
	11x8	0.20	0.74	7.3	6.7	1.0	5.0	30.0	2.0
	Mean	0.32	1.65	6.7	5.9	0.7	7.7	33.1	2.1

Table 19. (Continued)

Clone	Cross	Yield (lb/plant) 1968	Yield (lb/plant) 1969	Spring vigor score[a] 1969	Spring vigor score[a] 1970	Plants winter-killed 1969	Growth habit score[b] 1968	Days to bloom 1969	Pod set score[c] 1969
R9-5	12x3	0.48	2.57	4.8	4.0	0.0	3.4	35.7	2.2
	12x5	0.46	2.51	4.7	4.8	1.3	3.0	33.4	2.4
	12x7	0.41	1.75	4.3	7.0	0.0	2.1	28.2	1.8
	Mean	0.45	2.25	4.6	5.3	0.4	2.8	32.1	2.1
R10-6	13x2	0.30	1.63	5.7	5.7	0.0	8.4	34.7	2.2
	13x4	0.42	1.96	5.8	4.7	0.0	7.9	33.0	1.3
	13x6	0.38	2.90	4.3	2.2	0.0	8.1	35.8	1.7
	13x7	0.27	1.62	3.8	5.2	0.0	2.2	30.6	2.0
	13x8	0.29	0.51	6.9	7.6	0.7	2.2	29.8	2.9
	Mean	0.34	1.71	5.3	5.1	0.1	5.8	32.4	2.0
R10-9	14x1	0.37	2.07	6.0	5.8	0.3	7.8	35.5	1.1
	14x3	0.41	1.86	5.4	6.0	0.0	5.2	34.0	2.0
	14x5	0.38	1.58	5.7	5.9	0.3	5.3	35.6	2.8
	14x7	0.30	1.27	4.7	6.3	0.0	3.1	28.4	1.4
	14x8	0.27	0.86	6.6	8.2	1.0	3.3	29.6	1.5
	14x9	0.22	0.45	7.8	7.8	1.3	4.7	30.0	2.3
	Mean	0.33	1.34	6.0	6.7	0.5	4.9	31.9	1.8
R10-12	15x4	0.38	1.88	5.8	4.4	0.0	7.0	35.8	2.2
	15x6	0.40	2.97	4.7	2.7	0.0	8.2	36.2	1.9
	15x8	0.30	1.17	5.9	4.7	0.7	3.4	30.2	1.8
	Mean	0.36	1.99	5.5	3.9	0.2	6.2	33.8	2.0

Table 19. (Continued)

Clone	Cross	Yield (lb/plant) 1968	Yield (lb/plant) 1969	Spring vigor score[a] 1969	Spring vigor score[a] 1970	Plants winter-killed 1969	Growth habit score[b] 1968	Days to bloom 1969	Pod set score[c] 1969
R14-5	16x1	0.37	1.50	5.7	4.9	0.0	8.1	36.8	2.7
	16x3	0.47	2.56	4.6	2.9	0.0	4.1	36.8	2.8
	16x5	0.41	1.79	5.6	4.9	0.0	6.0	34.5	3.0
	16x7	0.18	1.34	5.1	5.0	0.0	3.2	31.5	1.4
	16x9	0.20	0.95	8.0	8.3	2.7	5.0	30.7	3.4
	Mean	0.33	1.62	5.8	5.2	0.5	5.5	33.8	2.7
R14-7	17x2	0.35	1.47	7.4	6.4	1.3	8.2	35.5	1.4
	17x4	0.52	1.94	5.3	3.8	0.0	6.6	37.4	1.9
	17x6	0.50	1.87	5.6	4.0	0.0	6.0	37.0	2.0
	17x8	0.39	0.45	8.6	8.2	2.7	1.1	31.6	2.6
	Mean	0.44	1.42	6.7	5.6	1.0	5.4	35.0	2.0
R22-3	18x1	0.34	0.99	6.9	5.4	0.3	6.8	40.1	2.3
	18x3	0.40	1.55	6.2	5.2	0.0	6.3	39.3	2.2
	18x5	0.47	1.24	6.7	6.7	1.0	6.4	39.8	3.5
	Mean	0.40	1.25	6.6	5.8	0.4	6.5	39.3	2.7
Check strains									
Empire		0.31	1.85	6.4	5.6	0.3	8.5	39.5	2.4
E-1		0.27	1.51	6.8	7.6	0.5	9.0	38.3	2.0
Russian		0.26	2.31	4.3	3.9	0.0	6.0	33.4	1.3
Carroll		0.36	1.80	5.4	5.3	0.0	6.2	34.3	2.4
Mean of check		0.30	1.86	5.7	5.6	0.2	7.4	36.4	2.0
L.S.D. (.05)		0.11	0.89	1.8	2.5	1.4	2.0	4.0	1.2

and 19. Individual comparisons were made of two-clone crosses with appropriate checks. Of 19, 18 and 39 progenies in Empire x Empire, Russian x Russian and Empire x Russian crosses, 0, 17, and 13 percent, respectively, exceeded significantly the high check in first-year forage yield. In the second harvest year, none of the two-clone combinations yielded significantly more than the best check strain. Similar results were obtained for spring vigor and winterhardiness. For growth habit, 26, 17 and 28 percent of F_1 progenies in Groups I, II and III, respectively, had scores significantly lower (more upright) than the score of the most upright check strain. None of the two-clone combinations in the three groups had scores significantly higher (more prostrate) than the score of the most prostrate check strain.

It was interesting to note that, in flowering date, none of the F_1 progenies were significantly later than the late check strain, but 5 percent of the crosses in each of Groups I and III bloomed earlier than the early check. None of the two-clone combinations produced significantly more pods than the most productive check strain.

Full-Sib Progenies

Mean values for agronomic characters of each full-sib progeny group and check strains are shown in Table 20. Analysis of variance mean squares for all traits measured in the test of full-sib progenies are shown in Table 21. Highly

Table 20. Mean values for agronomic characters of each full-sib progeny group and check strains

Group	Material	Yield (lb/plant) 1970	Spring vigor score[a] 1970	Plants winterkilled 1970	Growth habit score[b] 1969	Days to bloom 1970	Pod set score[c] 1970
I	Empire (E) FS_1's	0.23 ± 0.02	7.5 ± 0.1	1.2 ± 0.1	5.8 ± 0.1	27.9 ± 0.5	7.8 ± 0.2
II	Russian (R) FS_1's	0.43 ± 0.02	6.4 ± 0.1	0.5 ± 0.1	6.8 ± 0.1	29.3 ± 0.5	6.9 ± 0.2
III	E x R FS_1's	0.47 ± 0.01	5.9 ± 0.1	0.1 ± 0.1	6.8 ± 0.1	28.8 ± 0.3	6.6 ± 0.1
Check strains							
	Empire	0.44 ± 0.20	6.6 ± 1.4	0.3 ± 0.9	8.6 ± 0.3	28.9 ± 4.7	7.2 ± 1.5
	E-1	0.34 ± 0.09	7.0 ± 0.6	0.3 ± 0.3	8.5 ± 0.2	27.2 ± 2.0	7.0 ± 0.6
	Russian	0.50 ± 0.09	5.4 ± 0.6	0.1 ± 0.3	6.8 ± 0.2	27.1 ± 2.0	7.0 ± 0.6
	Carroll	0.70 ± 0.09	4.0 ± 0.6	0.0 ± 0.3	7.3 ± 0.2	26.5 ± 2.0	4.9 ± 0.6
Mean of checks		0.50 ± 0.05	5.8 ± 0.3	0.2 ± 0.2	7.8 ± 0.2	27.4 ± 1.1	6.4 ± 0.3

[a] Scored 1-9; 1 = most vigorous, 9 = least vigorous.

[b] Scored 1-9; 1 = upright, 9 = prostrate.

[c] Scored 1-9; 1 = good, 9 = poor.

Table 21. Analyses of variance for agronomic characters in full-sib progenies

Source of variation	df	Mean squares: Forage yield	Growth habit	Plants winterkilled	Spring vigor	Days to bloom	Pod set
		(1)	(2)	(3)	(4)	(5)	(6)
Replications	2	0.086*	6.135**	0.653	1.879	19.19	8.89**
Entries	99	0.186**	8.567**	2.871**	7.296**	30.23**	4.52**
Empire FS_1 progenies[a]	23	0.087**	8,950**	7.159**	5.567**	54.53**	2.38**
Among families	3	0.336**	4.636**	39.851**	26.292**	297.24**	5.64**
Within 3x6	5	0.023	1.547*	2.435**	2.853*	27.29*	1.50
Within 3x8	5	0.078**	3.244**	1.122*	3.622**	7.06	0.32
Within 5x6	5	0.091**	0.956	0.189	2.807*	17.59	3.77**
Within 5x8	5	0.008	7.611**	4.244**	0.552	20.55	1.99
Russian FS_1 progenies[b]	23	0.158**	12.741**	2.608**	7.516**	23.08**	5.91**
Among families	3	0.935**	89.784**	6.569**	40.917**	67.91**	36.43**
Within 12x13	5	0.003	1.655*	0.489	0.362	26.46*	1.57
Within 12x17	5	0.078**	0.629	0.000	2.012*	19.94	1.44
Within 13x18	5	0.037	0.988	0.000	2.364*	12.59	2.24
Within 17x18	5	0.050*	1.465*	7.567**	5.285**	6.46	0.06

[a]S.E. for 1, 2, 3, 4, 5 and 6 are 0.024, 2.530, 2.024, 1.455, 15.42 and 0.673, respectively.

[b]S.E. for 1, 2, 3, 4, 5 and 6 are 0.044, 3.603, 0.737, 2.125, 6.52 and 1.671, respectively.

*Significant at the .05 level of probability.

**Significant at the .01 level of probability.

Table 21. (Continued)

Source of variation	df	Mean squares: Forage yield	Growth habit	Plants winterkilled	Spring vigor	Days to bloom	Pod set
		(1)	(2)	(3)	(4)	(5)	(6)
ExR FS_1 progenies[c]	43	0.217**	5.551**	0.177	5.915**	22.95**	3.35**
Among families	7	0.780**	29.754**	0.179	18.869**	68.15**	7.45**
Within 3x12	5	0.035	0.544	0.233	1.071	36.91**	2.79*
Within 3x18	5	0.164**	0.458	0.056	4.677**	6.44	2.99*
Within 5x12	3	0.054*	0.122	0.111	0.884	10.84	2.56
Within 5x18	5	0.083**	0.547	0.056	3.168**	9.54	4.88**
Within 6x13	4	0.476**	0.072	0.000	8.725**	4.13	3.39*
Within 6x17	4	0.016	3.710**	0.267	2.009*	18.00	1.89
Within 8x13	5	0.007	0.779	0.189	0.328	19.83	1.11
Within 8x17	5	0.062*	0.783	0.456	6.341**	5.07	0.84
Checks	7	0.072**	2.003**	0.184	5.396**	8.23	4.46**
Checks vs others	1	0.159**	36.006**	1.973*	10.286**	53.77*	8.42**
(E FS_1, R FS_1) vs (E x R FS_1)	1	1.422**	40.248**	15.339**	48.720**	98.77**	31.87**
(E FS_1) vs (R FS_1)	1	1.371**	20.221**	33.393**	70.161**	1.89	40.68**
Error	198	0.020	0.604	0.401	0.965	11.15	1.09
C.V. (%)		(35.2)	(11.6)	(130.7)	(15.3)	(11.4)	(15.0)

[c]S.E. for 1, 2, 3, 4, 5 and 6 are 0.045, 1.170, 0.037, 1.247, 4.83 and 0.706, respectively.

significant differences among entries were observed for all traits studied.

The magnitude of the mean squares for progenies within each group differed considerably among the three groups. This indicated differences among groups in genetic variability. Similar to the F_1 population, the largest mean square for forage yield was found in Group III. Group II had the largest mean square for spring vigor, growth habit and pod production. The largest mean square for winterhardiness and days to bloom was found in Group I.

Among Empire x Empire full-sib progenies, crosses within 5 x 6 had the largest mean square for forage yield and pod set. Crosses within 5 x 8 had the largest mean square for growth habit and plants winterkilled. The largest mean square for spring vigor and days to bloom was found, respectively, among crosses within 3 x 8 and 3 x 6.

Among Russian x Russian full-sib progenies, crosses within the following F_1 families gave the largest mean square: 12 x 17 for yield, 12 x 13 for growth habit and days to bloom, and 17 x 18 for vigor and winterhardiness. Variation among full-sib progenies within F_1 families was not significant for pod set.

Crosses within 4 of 8 F_1 families accounted for the largest proportion of the variation in agronomic traits in the full-sib progenies within the Empire x Russian group. These were: 6 x 13 for yield and vigor, 6 x 17 for growth habit, 3 x 12 for days to bloom, and 5 x 18 for pod set. Variation among progenies within F_1 families for winterhardiness in this group was not significant.

Group comparisons were made between checks and full-sib progenies, between inter- and intrasource full-sib progenies and between the two groups of intrasource full-sib progenies (Table 21). When compared as groups, the performance of full-sib progenies was poorer than that of the check strains. They were less winterhardy, less vigorous and, consequently, gave lower yield than the checks. They were characterized as being more erect in growth habit and later maturing than the checks. The forage yield of Empire x Empire full-sib progenies was lower, but they were more upright than the original population (Empire).

Highly significant differences for all characters were found between the intersource and intrasource full-sib progeny means. Similar to the F_1 population, intersource progenies were superior in yield and vigor to the intrasource progenies. In addition, intersource progenies were more winterhardy and produced more pods than the intrasource progenies. Superiority in the latter two characters were not manifested in the F_1 population. Intersource progenies were more decumbent in growth habit than intrasource progenies, as a group.

As in the F_1 population, average performance of Russian x Russian full-sib progenies was significantly better than Empire x Empire progenies for yield, spring vigor, winterhardiness and pod production. The Empire group was more upright in growth habit and earlier maturing than the Russian group.

The agronomic performance of individual full-sib progenies in the three groups is presented in Tables 22, 23, and 24. Comparisons of individual progenies with the check strains were made. Of 24 progenies in each intrasource group, none were significantly better in yield than the high check. Twenty-nine and four percent, respectively, of the progenies in the Empire x Empire and Russian x Russian groups gave yields significantly lower than the low check strain. In contrast, 11 percent of the progenies in the intersource group, Empire x Russian, significantly outyielded the high check strain and none produced yields significantly lower than the low check. Similar results were obtained for spring vigor.

For growth habit, 46 percent of the full-sib progenies in the Empire x Empire group were significantly more upright than the most upright check. None were more decumbent than the most decumbent check. In the Russian x Russian and Empire x Russian groups, 25 and 27 percent, respectively, of the progenies had scores significantly lower (more upright) than the score of the low check strain, but none were significantly more prostrate than the most prostrate check.

For days to bloom, 8 and 9 percent, respectively, of the progenies in the Empire x Empire and Empire x Russian groups flowered significantly later than the latest check. In the Russian x Russian group, none of the progenies bloomed

Table 22. Mean performance of sib-crosses in the Empire group

Parent cross	Sib-cross	Yield (lb/ plant)	Spring vigor score[a]	Plants winter-killed	Growth habit score[b]	Days to bloom	Pod set score[c]
3x6	2x4	0.17	8.0	2.3	6.8	34.9	8.8
	4x9	0.16	7.6	0.7	7.2	32.0	7.7
	9x11	0.19	7.9	0.7	7.6	35.6	8.5
	11x14	0.36	5.7	0.0	8.6	31.0	6.8
	14x16	0.34	6.3	0.0	8.6	27.3	7.6
	16x2	0.24	6.4	0.0	7.9	33.6	7.6
	Mean	0.24	7.0	0.6	7.8	32.4	7.8
3x8	2x4	0.38	6.9	0.0	5.4	23.0	8.0
	4x8	0.07	8.4	1.0	2.9	25.8	8.2
	8x10	0.05	9.1	1.3	2.7	24.0	7.7
	10x14	0.22	7.3	0.0	4.4	21.4	7.4
	14x16	0.28	7.7	0.0	4.0	22.2	7.3
	16x2	0.45	6.0	0.0	4.3	23.5	7.8
	Mean	0.24	7.5	0.4	4.0	23.3	7.7
5x6	2x4	0.29	6.5	0.3	5.3	29.6	7.1
	4x8	0.47	4.9	0.0	6.4	32.6	8.0
	8x10	0.22	7.6	0.7	6.0	27.0	8.3
	10x15	0.19	7.3	0.3	6.3	32.6	8.2
	15x17	0.47	6.0	0.0	7.0	30.5	6.2
	17x2	0.64	6.0	0.3	5.9	27.6	5.6
	Mean	0.38	6.4	0.3	6.2	30.0	7.2
5x8	2x4	0.04	9.2	4.3	5.3	25.0	8.3
	4x7	0.05	9.0	2.3	5.0	28.5	8.8
	7x10	0.15	8.4	1.3	6.4	23.7	7.6
	10x14	0.03	9.3	3.3	7.3	29.5	8.3
	14x16	0.00	9.7	4.7	4.1	22.9	9.0
	16x2	0.03	9.5	4.3	2.9	26.0	8.3
	Mean	0.05	9.2	3.4	5.2	25.9	8.6

[a]Scored 1-9; 1 = most vigorous, 9 = least vigorous.

[b]Scored 1-9; 1 = upright, 9 = prostrate.

[c]Scored 1-9; 1 = good, 9 = poor.

Table 22. (Continued)

Parent cross	Sib-cross	Yield (lb/ plant)	Spring vigor score[a]	Plants winter-killed	Growth habit score[b]	Days to bloom	Pod set score[c]
Check strains							
	Empire	0.44	6.6	0.3	8.6	28.9	7.2
	E-1	0.34	7.0	0.3	8.5	27.2	7.0
	Russian	0.50	5.4	0.1	6.8	27.1	6.6
	Carroll	0.70	4.0	0.0	7.3	26.5	4.9
Mean of checks		0.50	5.8	0.2	7.8	27.4	6.4
L.S.D. (.05)		0.23	1.6	1.0	1.3	5.4	1.7

significantly earlier than the early check, and none later than the latest check. For pod production, none of the progenies from the three groups were significantly better or poorer than the high or low checks.

A summary of the performance of sib-crosses within each F_1 family is shown in Table 25. Marked differences among F_1 families in the performance of full-sib progenies were observed. Full-sib progenies of 3 x 18 and 6 x 13 (both from Empire x Russian) were the most vigorous and highest yielding, followed by 13 x 18 (Russian x Russian). These crosses also were among the most winterhardy, produced the most pods in two instances, and were decumbent in growth habit. Full-sib progenies obtained from Empire x Empire families performed poorly in yield, vigor and winterhardiness.

Table 23. Mean performance of sib-crosses in the Russian group

Parent cross	Sib-cross	Yield (lb/plant)	Spring vigor score[a]	Plants winter-killed	Growth habit score[b]	Days to bloom	Pod set score[c]
12x13	2x4	0.24	7.8	0.7	4.0	29.1	7.4
	4x8	0.28	7.2	0.3	4.2	23.2	6.0
	8x10	0.21	8.0	1.0	3.3	28.4	7.3
	10x14	0.20	8.1	1.3	4.3	29.6	8.2
	14x16	0.22	7.6	0.7	3.6	27.3	7.7
	16x2	0.18	7.8	1.3	2.3	22.9	6.9
	Mean	0.22	7.7	0.9	3.6	25.5	7.2
12x17	2x4	0.57	4.8	0.0	8.9	27.0	8.3
	4x8	0.52	5.1	0.0	8.7	30.2	7.9
	8x10	0.44	6.0	0.0	8.0	27.7	7.7
	10x14	0.45	5.4	0.0	8.7	33.3	8.7
	14x16	0.58	5.1	0.0	8.3	32.6	6.8
	16x2	0.88	3.6	0.0	7.7	29.0	7.3
	Mean	0.58	5.0	0.0	8.4	30.0	7.8
13x18	2x4	0.49	6.0	0.0	8.3	32.4	4.4
	4x8	0.62	5.6	0.0	7.6	28.6	4.4
	8x10	0.68	5.3	0.0	7.8	33.5	5.6
	10x15	0.74	5.0	0.0	8.9	28.4	5.8
	15x17	0.66	5.4	0.0	8.9	29.9	3.6
	17x2	0.82	3.4	0.0	8.7	30.7	5.1
	Mean	0.67	5.1	0.0	8.4	30.5	4.8
17x18	8x9	0.03	9.6	4.3	6.1	32.3	8.0
	9x11	0.20	7.8	1.0	7.8	28.8	7.8
	11x14	0.30	7.7	0.7	7.6	30.4	7.8
	14x15	0.34	7.4	0.7	6.3	32.7	7.9
	15x17	0.39	5.4	0.0	7.3	30.2	7.6
	17x8	0.19	7.7	0.3	6.6	31.7	7.7
	Mean	0.24	7.6	1.2	6.9	31.0	7.8

[a]Scored 1-9; 1 = most vigorous, 9 = least vigorous.

[b]Scored 1-9; 1 = upright, 9 = prostrate.

[c]Scored 1-9; 1 = good, 9 = poor.

Table 23. (Continued)

Parent cross	Sib-cross	Yield (lb/ plant)	Spring vigor score[a]	Plants winter-killed	Growth habit score[b]	Days to bloom	Pod set score[c]
Check strains							
	Russian	0.50	5.4	0.1	6.8	27.1	6.6
	Carroll	0.70	4.0	0.0	7.3	26.5	4.9
	Empire	0.44	6.6	0.3	8.6	28.9	7.2
	E-1	0.34	7.0	0.3	8.5	27.2	7.0
Mean of checks		0.50	5.8	0.2	7.8	27.4	6.4
L.S.D. (.05)		0.23	1.6	1.0	1.3	5.4	1.7

Intercharacter Correlation

Phenotypic correlation coefficients between characters in F_1 and full-sib progenies are shown in Table 26. Correlation coefficients were calculated from entry means. Negative correlation values for association of other characters with either spring vigor or pod set represent positive relationships because of the method of scoring (1 = best; 9 = poorest). Considerable variation between F_1 and full-sib progenies often existed in the degree of correlation between a pair of characters. In general, the magnitude of the coefficients and the frequency of significance increased as the population became inbred.

Certain characters were associated closely among both types of progenies. Yield was closely and significantly correlated with spring vigor and winterhardiness. Yield also

Table 24. Mean performance of sib-crosses in the Empire x Russian group

Parent cross	Sib-cross	Yield (lb/ plant)	Spring vigor score[a]	Plants winter-killed	Growth habit score[b]	Days to bloom	Pod set score[c]
3x12	2x4	0.29	6.9	0.7	6.3	27.6	6.5
	4x8	0.38	6.0	0.0	6.4	25.6	7.1
	8x10	0.20	6.8	0.3	6.3	35.7	8.0
	10x15	0.17	7.4	0.0	6.8	28.9	8.2
	15x17	0.36	6.0	0.0	7.1	28.5	6.7
	17x2	0.45	6.0	0.0	7.3	31.4	5.7
	Mean	0.31	6.5	0.2	6.7	29.6	7.0
3x18	2x5	1.07	3.4	0.0	9.0	27.9	5.0
	5x8	0.94	3.8	0.0	8.4	30.9	6.7
	8x10	1.09	3.0	0.0	8.2	26.5	5.2
	10x14	0.59	5.5	0.3	8.9	28.6	6.7
	14x16	0.54	6.1	0.0	8.3	27.5	5.6
	16x2	0.80	3.7	0.0	8.0	28.0	4.2
	Mean	0.84	4.2	0.0	8.5	28.2	5.6
5x12	8x10	0.20	7.6	0.3	5.1	25.6	7.4
	10x15	0.53	6.4	0.3	4.8	24.0	5.2
	15x17	0.33	6.8	0.0	4.9	27.9	6.2
	17x2	0.37	6.6	0.0	5.2	27.8	6.5
	Mean	0.36	6.8	0.2	5.0	26.3	6.3
5x18	2x5	0.76	4.1	0.0	6.9	29.7	4.8
	5x8	0.54	5.9	0.3	7.3	26.7	6.0
	8x10	0.65	4.7	0.0	7.7	26.9	5.8
	10x15	0.80	6.6	0.0	8.0	29.1	8.2
	15x17	0.41	6.7	0.0	7.0	30.7	7.7
	17x2	0.51	5.8	0.0	7.1	30.8	6.9
	Mean	0.53	5.6	0.0	7.3	28.9	6.6

[a]Scored 1-9; 1 = most vigorous, 9 = least vigorous.

[b]Scored 1-9; 1 = upright, 9 = prostrate.

[c]Scored 1-9; 1 = good, 9 = poor.

Table 24. (Continued)

Parent cross	Sib-cross	Yield (lb/ plant)	Spring vigor score[a]	Plants winter-killed	Growth habit score[b]	Days to bloom	Pod set score[c]
6x13	2x4	0.33	6.0	0.0	8.3	30.3	8.7
	8x10	0.35	6.6	0.0	8.7	28.3	7.6
	10x14	0.78	4.1	0.0	8.4	31.1	6.6
	14x16	0.93	4.5	0.0	8.3	28.7	7.2
	16x2	1.27	2.2	0.0	8.6	29.1	5.8
	Mean	0.73	4.7	0.0	8.4	29.4	7.2
6x17	2x4	0.28	7.3	0.7	4.0	27.7	6.8
	4x8	0.29	7.4	0.0	6.3	25.2	6.9
	8x10	0.45	6.9	0.0	6.4	26.6	5.4
	15x17	0.39	5.8	0.0	4.8	31.7	7.6
	17x2	0.38	5.8	0.0	4.7	28.1	6.2
	Mean	0.36	6.6	0.1	5.2	27.8	6.6
8x13	2x4	0.33	7.0	0.0	7.4	31.8	6.5
	4x8	0.22	6.8	0.3	7.8	36.9	8.0
	8x10	0.18	7.7	0.7	8.0	30.1	8.2
	10x14	0.22	7.2	0.0	6.7	33.0	7.6
	14x16	0.24	7.2	0.3	7.4	34.8	7.9
	16x2	0.23	7.6	0.3	6.9	30.8	7.4
	Mean	0.24	7.2	0.3	7.4	32.9	7.6
8x17	2x4	0.21	7.9	1.0	4.9	25.3	6.7
	4x7	0.43	6.0	0.3	5.4	27.5	5.4
	7x9	0.58	3.6	0.0	5.4	26.5	6.6
	9x14	0.53	5.3	0.0	5.4	29.2	5.7
	14x16	0.30	6.1	0.0	6.4	26.5	5.6
	16x2	0.31	6.6	0.3	5.5	26.9	6.0
	Mean	0.39	5.9	0.3	5.5	26.9	6.0
Check strains							
	Empire	0.44	6.6	0.3	8.6	28.9	7.2
	E-1	0.34	7.0	0.3	8.5	27.2	7.0
	Russian	0.50	5.4	0.1	6.8	27.1	6.6
	Carroll	0.70	4.0	0.0	7.3	26.5	4.9
Mean of checks		0.50	5.8	0.2	7.8	27.4	6.4
L.S.D. (.05)		0.23	1.6	1.0	1.3	5.4	1.7

Table 25. Summary of the performance of sib-crosses in each F_1 family

Group	F_1 family	Yield (lb/ plant)	Spring vigor score[a]	Plants winter-killed	Growth habit score[b]	Days to bloom	Pod set score[c]
Empire (E)	3x6	0.24	7.0	0.6	7.8	32.4	7.8
	3x8	0.24	7.6	0.4	4.0	23.2	7.7
	5x6	0.38	6.4	0.3	6.2	30.0	7.2
	5x8	0.05	9.2	3.4	5.2	25.9	8.6
Russian (R)	12x13	0.22	7.7	0.9	3.6	25.6	7.2
	12x17	0.58	5.0	0.0	8.4	30.0	7.8
	13x18	0.67	5.1	0.0	8.4	30.6	4.8
	17x18	0.24	7.6	1.2	6.9	31.0	7.8
E x R	3x12	0.31	6.5	0.2	6.7	29.6	7.0
	3x18	0.84	4.2	0.1	8.5	28.2	5.6
	5x12	0.35	6.8	0.2	5.0	26.3	6.3
	5x18	0.53	5.6	0.1	7.3	28.9	6.6
	6x13	0.73	4.7	0.0	8.5	29.4	7.2
	6x17	0.35	6.6	0.1	5.2	27.8	6.6
	8x13	0.24	7.2	0.3	7.4	32.9	7.6
	8x17	0.39	5.9	0.3	5.5	26.9	6.0
Check strains							
	Empire	0.44	6.6	0.3	8.6	28.9	7.2
	E-1	0.34	7.0	0.3	8.5	27.2	7.0
	Russian	0.50	5.4	0.1	6.8	27.1	6.6
	Carroll	0.70	4.0	0.0	7.3	26.5	4.9
Mean of checks		0.50	5.8	0.2	7.8	27.4	6.4

[a]Scored 1-9; 1 = most vigorous, 9 = least vigorous.

[b]Scored 1-9; 1 = upright, 9 = prostrate.

[c]Scored 1-9; 1 = good, 9 = poor.

Table 26. Phenotypic correlation coefficients between agronomic characters of F_1 progenies (above diagonal) and full-sib progenies (below diagonal)

Character	Yield[a]	Spring vigor 1969	Spring vigor 1970	Plants winter-killed	Growth habit	Days to bloom	Pod set	Seed size
Yield, 1968	0.48**[b]	-0.37**	-0.53**	-0.33**	-0.07	0.30**	0.07	-0.23*
Yield, 1969	--	-0.82**	-0.80**	-0.68**	0.26*	0.35**	-0.32**	-0.36**
Spring vigor, 1969	--	--	0.79**	0.76**	0.06	-0.03	0.31**	0.20
Spring vigor, 1970	-0.93**[c]	--	--	0.71**	-0.07	-0.25*	0.17	0.17
Plants winterkilled	-0.54**	--	0.67**	--	-0.39**	-0.33**	0.20	0.38**
Growth habit	0.53**	--	-0.54**	-0.39**	--	0.61**	-0.01	-0.47**
Days to bloom	0.04	--	-0.12	-0.13	0.45**	--	0.19	-0.34**
Pod set	-0.64**	--	0.60**	0.45**	-0.22*	0.13	--	0.09

[a]1969 yield for F_1 progenies, 1970 yield for full-sib progenies.

[b]df = 74.

[c]df = 90

*Significant at the .05 level of probability.

**Significant at the .01 level of probability.

showed a tendency to be associated with a more prostrate growth habit and good pod production. In addition to its association with high yield, winterhardiness was associated with good spring vigor and relatively prostrate growth habit. Late maturity appears to be associated with decumbency.

Some characters were associated in one generation but not in the other. For instance, late maturity tended to be associated with good spring vigor, winterhardiness and high forage yield in the F_1 but not in the full-sib progenies. On the other hand, decumbency was associated with good spring vigor and seed production, and good seed production was associated with good spring vigor and winterhardiness in the full-sib progenies but not in the F_1.

Using F_1 data, large seed size was associated with upright growth habit, early maturity, relatively poor winterhardiness, and low yield. Although the negative associations of seed size with forage yield and winterhardiness were significant, the r^2 values were rather small (5-14 percent). Seed size was independent of seed load.

Seed Size and Progeny Seedling Vigor Studies

General analysis

Mean values for seed size and progeny seedling vigor traits of each F_1 group and check strains are presented in Table 27, and the analyses of variance are shown in Table 28. Significant differences were found among entries for all traits

Table 27. Mean values for seed size and progeny seedling vigor traits in each F_1 group

Group	Material	Seed size ml/100 seeds x 100	Dry weight g/seedling x 100	Radicle length mm	Hypocotyl length mm	R + H length mm
I	Empire (E) F_1's	21.7 ± 0.0006	.076 ± .0008	1.9 ± 0.05	5.0 ± 0.08	6.9 ± 0.08
II	Russian (R) F_1's	19.4 ± 0.0006	.062 ± .0005	1.7 ± 0.05	4.9 ± 0.08	6.6 ± 0.08
III	E x R F_1's	20.7 ± 0.0006	.069 ± .0005	1.8 ± 0.03	5.2 ± 0.05	7.0 ± 0.05
Check strains						
	Empire	14.4 ± 0.020	.052 ± .0255	1.3 ± 0.42	4.4 ± 0.71	5.7 ± 0.73
	E-1	17.6 ± 0.008	.056 ± .0020	1.5 ± 0.17	4.8 ± 0.30	6.3 ± 0.31
	Russian	18.4 ± 0.020	.054 ± .0255	1.6 ± 0.42	5.2 ± 0.71	6.8 ± 0.73
	Carroll	18.2 ± 0.020	.064 ± .0255	1.6 ± 0.42	4.9 ± 0.71	6.5 ± 0.73
Mean of checks		17.2 ± 0.001	.056 ± .0010	1.5 ± 0.09	4.8 ± 0.16	6.3 ± 0.16

Table 28. Analyses of variance for seed size and progeny seedling vigor traits

Source of variation	df	Mean squares				
		Seed size	Dry weight	Radicle length	Hypocotyl length	R + H length
		(1)	(2)	(3)	(4)	(5)
Replications	2	0.0007*	0.00858	0.45922	0.49804	0.60937
Entries	80	0.0015**	0.00027**	0.1360**	0.3753*	0.579**
Empire (E) F_1's[a]	18	0.0014**	0.00023**	0.1713**	0.4128*	0.742**
Russian (R) F_1's[b]	17	0.0011**	0.00019*	0.0115	0.2644	0.350
E x R F_1's[c]	38	0.0012**	0.00018*	0.0968	0.3410	0.443**
Check strains	4	0.0009**	0.00023	0.0456	0.2430	0.706*
Checks vs others	1	0.0165**	0.00112**	1.0648**	0.6959	1.761**
(E,R) vs (ExR)	1	0.0001	0.00000	0.0398	2.7935**	2.167**
Empire vs Russian	1	0.0138**	0.00509**	0.8149**	0.5059	2.608**
Error	160	0.0002	0.00012	0.0840	0.2441	0.260
C.V. (%)		(7.0)	(15.8)	(16.5)	(9.8)	(7.5)

[a]S.E. for 1, 2, 3, 4 and 5 are .0001, .00002, .0542, .0413 and .224, respectively.

[b]S.E. for 1, 2, 3, 4 and 5 are .0001, .00002, .0012, .0191 and .113, respectively.

[c]S.E. for 1, 2, 3, 4 and 5 are .0002, .00001, .0068, .0170 and .099, respectively.

*Significant at the .05 level of probability.

**Significant at the .01 level of probability.

studied.

The magnitude of the mean squares for progenies differed considerably among hybrid groups. Empire x Empire crosses had the largest mean square for seed size and all seedling traits, while Russian x Russian crosses usually had the smallest.

Orthogonal comparisons (Table 28) indicated that the crosses were significantly better than the check strains as a group in all seed and seedling traits, except for hypocotyl length. As expected, the Empire x Empire F_1 progenies were superior to the original population (Empire) in all seed and seedling traits. Superiority of the Russian x Russian F_1 progenies over the original population (Russian) was manifested only in seed size and dry weight but not for the other seedling traits.

Crosses between sources were superior in hypocotyl and total seedling length to crosses within sources. Empire x Empire crosses were significantly superior to Russian x Russian crosses in all seed and seedling traits except for hypocotyl length.

Combining ability studies

General and specific combining ability mean squares for all seed and seedling traits in the three hybrid groups are given in Tables 29, 30 and 31. General combining ability mean squares were significant for all traits, except for dry weight and radicle length in Empire x Russian crosses.

Table 29. General and specific combining ability mean squares for seed size and progeny seedling vigor traits for Empire x Empire partial diallel

		Mean squares				
Source	df	Seed size	Dry weight	Radicle length	Hypocotyl length	R+H length
GCA	8	0.0029**	0.00035**	0.290**	0.618**	1.248**
SCA	10	0.0002	0.00013	0.076	0.249	0.338
Error	160	0.0002	0.00012	0.084	0.244	0.260

**Significant at the .01 level of probability.

Table 30. General and specific combining ability mean squares for seed size and progeny seedling vigor traits for Russian x Russian partial diallel

		Mean squares				
Source	df	Seed size	Dry weight	Radicle length	Hypocotyl length	R+H length
GCA	8	0.0022**	0.00031**	0.161*	0.455*	0.652**
SCA	9	0.0001	0.00008	0.074	0.095	0.082
Error	160	0.0002	0.00012	0.084	0.244	0.260

*Significant at the .05 level of probability.

**Significant at the .01 level of probability.

Table 31. General and specific combining ability mean squares for seed size and progeny seedling vigor traits for Empire x Russian partial diallel

		Mean squares				
Source	df	Seed size	Dry weight	Radicle length	Hypocotyl length	R+H length
GCA (Empire)	8	0.0015**	0.00021	0.211**	0.648**	0.920**
GCA (Russian)	8	0.0024**	0.00031**	0.078	0.590*	0.625*
SCA (E x R)	22	0.0003	0.00006	0.047	0.167	0.174
Error	160	0.0002	0.00012	0.084	0.244	0.260

*Significant at the .05 level of probability.

**Significant at the .01 level of probability.

Specific combining ability mean squares were not significant.

Average performance for seed size and progeny seedling vigor traits of 18 Empire and Russian parent clones in crosses within and between sources are presented in Tables 32 and 33. The Empire clone, E20-21, was the best clone in both intra- and intersource crosses for seed size and seedling dry weight. E20-15 was generally the second best performing clone in both types of crosses. The Russian clone, R14-5, performed well in intersource crosses.

Performance of individual F_1 progenies and check strains is shown in Tables 34, 35 and 36. Comparisons were made of

Table 32. Average performance for seed size and progeny seedling vigor traits of Empire and Russian clones in intrasource crosses

Clone No.	Clone Name	Seed size ml/100 seeds x 100	Dry weight g/seedling x 100	Radicle length mm	Hypocotyl length mm	R + H length mm
1	E4-1	20.5 ± 0.002	.068 ± .001	1.8 ± 0.06	5.2 ± 0.2	7.0 ± 0.2
2	E4-8	21.0 ± 0.001	.072 ± .001	1.8 ± 0.06	4.9 ± 0.1	6.7 ± 0.1
3	E12-1	21.8 ± 0.001	.076 ± .001	1.8 ± 0.06	4.7 ± 0.2	6.6 ± 0.2
4	E12-14	20.2 ± 0.001	.073 ± .001	1.8 ± 0.06	4.7 ± 0.2	6.6 ± 0.2
5	E15-2	21.3 ± 0.001	.076 ± .001	1.8 ± 0.06	4.9 ± 0.2	6.7 ± 0.2
6	E15-15	20.8 ± 0.002	.077 ± .001	1.6 ± 0.12	5.0 ± 0.2	6.6 ± 0.2
7	E20-14	21.2 ± 0.002	.079 ± .001	2.0 ± 0.06	4.9 ± 0.2	6.8 ± 0.2
8	E20-15	23.4 ± 0.001	.081 ± .001	2.1 ± 0.06	5.3 ± 0.2	7.3 ± 0.2
9	E20-21	25.5 ± 0.002	.085 ± .002	2.0 ± 0.12	5.3 ± 0.2	7.3 ± 0.2
10	R6-8	18.5 ± 0.001	.059 ± .001	1.5 ± 0.06	4.9 ± 0.2	6.4 ± 0.2
11	R6-18	19.7 ± 0.001	.065 ± .001	1.8 ± 0.06	4.8 ± 0.2	6.6 ± 0.2
12	R9-5	18.6 ± 0.002	.057 ± .002	1.6 ± 0.12	4.7 ± 0.2	6.3 ± 0.2
13	R10-6	20.1 ± 0.001	.067 ± .001	1.6 ± 0.06	5.0 ± 0.2	6.6 ± 0.2
14	R10-9	20.8 ± 0.002	.066 ± .002	1.7 ± 0.12	5.2 ± 0.2	6.8 ± 0.2

Table 32. (Continued)

Clone No.	Clone Name	Seed size ml/100 seeds x 100	Dry weight g/seedling x 100	Radicle length mm	Hypocotyl length mm	R + H length mm
15	R10-12	18.8 ± 0.020	.053 ± .025	1.5 ± 0.40	5.1 ± 0.69	6.6 ± 0.69
16	R14-5	21.4 ± 0.002	.070 ± .002	1.9 ± 0.06	4.9 ± 0.20	6.8 ± 0.20
17	R14-7	19.6 ± 0.002	.062 ± .001	1.7 ± 0.06	4.8 ± 0.10	6.5 ± 0.10
18	R22-3	17.2 ± 0.002	.056 ± .002	1.6 ± 0.06	4.4 ± 0.20	6.1 ± 0.20
Check strains						
	Empire	14.4 ± 0.020	.052 ± .025	1.3 ± 0.4	4.4 ± 0.69	5.7 ± 0.75
	E-1	17.6 ± 0.009	.056 ± .002	1.5 ± 0.2	4.8 ± 0.29	6.3 ± 0.29
	Russian	18.4 ± 0.020	.054 ± .025	1.6 ± 0.4	5.2 ± 0.69	6.8 ± 0.75
	Carroll	18.2 ± 0.020	.064 ± .025	1.6 ± 0.4	4.9 ± 0.69	6.5 ± 0.75
Mean of checks		17.2 ± 0.001	.056 ± .001	1.5 ± 0.1	4.8 ± 0.20	6.3 ± 0.20

Table 33. Average performance for seed size and progeny seedling vigor traits of Empire and Russian clones in intersource crosses

Clone No.	Clone Name	Seed size ml/100 seeds x 100	Dry weight g/seedling x 100	Radicle length mm	Hypocotyl length mm	R + H length mm
1	E4-1	19.0 ± 0.002	.062 ± .002	1.6 ± 0.06	5.4 ± 0.20	7.1 ± 0.20
2	E4-8	20.8 ± 0.002	.068 ± .001	1.7 ± 0.12	5.4 ± 0.20	7.1 ± 0.20
3	E12-1	19.9 ± 0.002	.069 ± .002	1.7 ± 0.06	5.0 ± 0.20	6.7 ± 0.20
4	E12-4	19.2 ± 0.002	.064 ± .002	1.6 ± 0.06	4.8 ± 0.20	6.5 ± 0.20
5	E15-2	20.4 ± 0.002	.068 ± .002	1.7 ± 0.06	5.1 ± 0.12	6.8 ± 0.12
6	E15-15	21.2 ± 0.002	.072 ± .002	1.6 ± 0.06	5.0 ± 0.20	6.6 ± 0.20
7	E20-14	20.9 ± 0.002	.070 ± .002	1.9 ± 0.06	5.1 ± 0.20	7.0 ± 0.20
8	E20-15	22.5 ± 0.002	.076 ± .002	2.0 ± 0.06	5.3 ± 0.20	7.2 ± 0.20
9	E20-21	24.2 ± 0.002	.081 ± .002	1.9 ± 0.20	5.3 ± 0.29	7.2 ± 0.29
10	R6-8	18.2 ± 0.002	.060 ± .002	1.6 ± 0.06	5.1 ± 0.20	6.7 ± 0.20
11	R6-18	20.9 ± 0.002	.070 ± .002	1.8 ± 0.06	4.9 ± 0.20	6.7 ± 0.20
12	R9-5	19.5 ± 0.002	.064 ± .002	1.8 ± 0.12	5.1 ± 0.20	6.9 ± 0.20
13	R10-6	21.4 ± 0.002	.072 ± .002	1.9 ± 0.06	4.9 ± 0.20	6.8 ± 0.20
14	R10-9	21.1 ± 0.002	.074 ± .002	1.8 ± 0.06	5.3 ± 0.12	7.1 ± 0.12

Table 33. (Continued)

Clone No.	Clone Name	Seed size ml/100 seeds x 100	Dry weight g/seedling x 100	Radicle length mm	Hypocotyl length mm	R + H length mm
15	R10-12	20.9 ± 0.020	.070 ± .025	1.7 ± 0.12	5.2 ± 0.2	6.9 ± 0.2
16	R14-5	23.6 ± 0.002	.077 ± .002	1.8 ± 0.06	5.4 ± 0.2	7.2 ± 0.2
17	R14-7	21.2 ± 0.002	.070 ± .001	1.7 ± 0.06	5.3 ± 0.2	7.0 ± 0.2
18	R22-3	18.4 ± 0.002	.061 ± .002	1.5 ± 0.12	4.9 ± 0.2	6.4 ± 0.2
Check strains	Empire	14.4 ± 0.020	.052 ± .025	1.3 ± 0.4	4.4 ± 0.69	5.7 ± 0.75
	E-1	17.6 ± 0.009	.056 ± .002	1.5 ± 0.2	4.8 ± 0.29	6.3 ± 0.29
	Russian	18.4 ± 0.020	.054 ± .025	1.6 ± 0.4	5.2 ± 0.69	6.8 ± 0.75
	Carroll	18.2 ± 0.020	.064 ± .025	1.6 ± 0.4	4.9 ± 0.69	6.5 ± 0.75
Mean of checks		17.2 ± 0.001	.056 ± .001	1.5 ± 0.1	4.8 ± 0.20	6.3 ± 0.75

Table 34. Mean performance for seed size and progeny seedling vigor traits in Empire x Empire crosses

Clone	Cross	Seed size ml/100 sds. x 100	Dry wt. g/sdlg. x 100	Radicle length mm	Hypocotyl length mm	R + H length mm
E4-1	1x2	18.9	.053	1.5	5.2	6.7
	1x4	20.2	.070	1.8	5.2	6.8
	1x7	21.5	.081	2.0	5.2	7.2
	1x8	21.3	.069	1.9	5.6	7.5
	Mean	20.5	.068	1.8	5.2	7.0
E4-8	2x1	18.9	.053	1.5	5.2	6.7
	2x3	20.2	.073	1.7	4.1	5.8
	2x5	20.0	.073	1.6	4.7	6.3
	2x7	21.5	.078	1.9	4.9	6.8
	2x8	21.4	.072	2.0	5.0	7.0
	2x9	24.1	.081	2.0	5.4	7.4
	Mean	21.0	.072	1.8	4.9	6.7
E12-1	3x2	20.2	.073	1.7	4.1	5.8
	3x4	19.1	.068	1.5	4.5	6.0
	3x6	21.3	.080	1.6	5.0	6.6
	3x8	23.0	.082	2.4	5.0	7.4
	3x9	25.3	.077	2.0	5.0	7.0
	Mean	21.8	.076	1.8	4.7	6.6
E12-14	4x1	20.2	.070	1.8	5.0	6.8
	4x3	19.1	.068	1.5	4.5	6.0
	4x5	20.7	.077	2.0	4.9	6.9
	4x7	20.8	.077	2.1	4.5	6.6
	Mean	20.2	.073	1.8	4.7	6.6
E15-2	5x2	20.0	.073	1.6	4.7	6.3
	5x4	20.7	.077	2.0	4.9	6.9
	5x6	20.3	.071	1.5	5.0	6.5
	5x8	24.3	.085	2.1	5.1	7.2
	Mean	21.3	.076	1.8	4.9	6.7
E15-15	6x3	21.3	.080	1.6	5.0	6.6
	6x5	20.3	.071	1.5	5.0	6.5
	6x7	20.9	.079	1.8	4.9	6.7
	Mean	20.8	.077	1.6	5.0	6.6

Table 34. (Continued)

Clone	Cross	Seed size ml/100 sds. x 100	Dry wt. g/sdlg. x 100	Radicle length mm	Hypocotyl length mm	R + H length mm
E20-14	7x1	21.5	.081	2.0	5.2	7.2
	7x2	21.5	.078	1.9	4.9	6.8
	7x4	20.8	.077	2.1	4.5	6.6
	7x6	20.9	.079	1.8	4.9	6.7
	Mean	21.2	.079	2.0	4.9	6.8
E20-15	8x1	21.3	.069	1.9	5.6	7.5
	8x2	21.4	.072	2.0	5.0	7.0
	8x3	23.0	.082	2.4	5.0	7.4
	8x5	24.3	.085	2.1	5.1	7.2
	8x9	27.0	.097	1.9	5.6	7.5
	Mean	23.4	.081	2.1	5.3	7.3
E20-21	9x2	24.1	.081	2.0	5.4	7.4
	9x3	25.3	.077	2.0	5.0	7.0
	9x8	27.0	.097	1.9	5.6	7.5
	Mean	25.5	.085	2.0	5.3	7.3
Check strains						
	Empire	14.4	.052	1.3	4.4	5.7
	E-1	17.6	.056	1.5	4.8	6.3
	Russian	18.4	.054	1.6	5.2	6.8
	Carroll	18.2	.064	1.6	4.9	6.5
Mean of checks		17.2	.056	1.5	4.8	6.3
L.S.D. (.05)		2.3	.018	0.5	0.8	0.8

Table 35. Mean performance for seed size and progeny seedling vigor traits in Russian x Russian crosses

Clone	Cross	Seed size ml/100 sds. x 100	Dry wt. g/sdlg. x 100	Radicle length mm	Hypocotyl length mm	R + H length mm
R6-8	10x11	17.7	.060	1.5	4.6	6.1
	10x13	18.4	.056	1.4	5.3	6.7
	10x15	18.8	.053	1.5	5.1	6.6
	10x16	19.4	.059	1.6	4.8	6.4
	10x17	18.2	.065	1.7	4.7	6.4
	Mean	18.5	.059	1.5	4.9	6.4
R6-18	11x10	17.7	.060	1.5	4.6	6.1
	11x14	21.0	.068	1.7	5.3	7.0
	11x16	22.0	.075	2.2	4.9	7.1
	11x17	20.3	.063	1.7	5.1	6.8
	11x18	17.6	.057	1.9	4.3	6.2
	Mean	19.7	.065	1.8	4.8	6.6
R9-5	12x13	20.2	.066	1.6	5.0	6.6
	12x17	20.0	.058	1.8	4.8	6.6
	12x18	15.5	.048	1.5	4.3	5.8
	Mean	18.6	.057	1.6	4.7	6.3
R10-6	13x10	18.4	.056	1.4	5.3	6.7
	13x12	20.2	.066	1.6	5.0	6.6
	13x14	20.8	.074	1.6	5.3	6.9
	13x16	23.4	.079	2.0	4.8	6.8
	13x18	17.9	.059	1.5	4.7	6.2
	Mean	20.1	.067	1.6	5.0	6.6
R10-9	14x11	21.0	.068	1.7	5.3	7.0
	14x13	20.8	.075	1.6	5.3	6.9
	14x17	20.7	.056	1.7	4.9	6.6
	Mean	20.8	.066	1.7	5.2	6.8
R10-12	15x10	18.8	.053	1.5	5.1	6.6
	Mean	18.8	.053	1.5	5.1	6.6
R14-5	16x10	19.4	.059	1.6	4.8	6.4
	16x11	22.0	.075	2.2	4.9	7.1
	16x13	23.4	.079	2.0	4.8	6.8
	16x17	20.7	.067	1.8	4.9	6.7
	Mean	21.4	.070	1.9	4.9	6.8

Table 35. (Continued)

Clone	Cross	Seed size ml/100 sds. x 100	Dry wt. g/sdlg. x 100	Radicle length mm	Hypocotyl length mm	R + H length mm
R14-7	17x10	18.2	.065	1.7	4.7	6.4
	17x11	20.3	.063	1.7	5.1	6.8
	17x12	20.0	.058	1.8	4.8	6.6
	17x14	20.7	.056	1.7	4.9	6.6
	17x16	20.7	.067	1.8	4.9	6.7
	17x18	17.6	.060	1.6	4.8	6.1
	Mean	19.6	.062	1.7	4.8	6.5
R22-3	18x11	17.6	.057	1.9	4.3	6.2
	18x12	15.5	.048	1.5	4.3	5.8
	18x13	17.9	.059	1.5	4.7	6.2
	18x17	17.6	.060	1.6	4.5	6.1
	Mean	17.2	.056	1.6	4.4	6.1
Check strains						
	Russian	18.4	.054	1.6	5.2	6.8
	Carroll	18.2	.064	1.6	4.9	6.5
	Empire	14.4	.052	1.3	4.4	5.1
	E-1	17.6	.056	1.5	4.8	6.3
Mean of checks		17.2	.056	1.5	4.8	6.3
L.S.D. (.05)		2.3	.018	0.5	0.8	0.8

individual F_1 progenies in each group with appropriate check strains. Sixty-eight, 33 and 56 percent of the F_1 progenies in Groups I, II, and III, respectively, produced seeds significantly larger than the largest seeded check; and none had seeds significantly smaller than the smallest seeded check. For dry weight, 21 and 10 percent of Empire x Empire and Empire x Russian progenies, respectively, had seedlings that significantly outweighed those of the check strain with the

Table 36. Mean performance for seed size and progeny seedling vigor traits in Empire x Russian crosses

Clone	Cross	Seed size ml/100 sds. x 100	Dry wt. g/sdlg. x 100	Radicle length mm	Hypocotyl length mm	R + H length mm
E4-1	1x10	16.8	.060	1.5	5.5	7.0
	1x14	19.7	.061	1.8	5.6	7.4
	1x16	21.8	.070	1.6	5.9	7.5
	1x18	17.9	.058	1.6	4.8	6.4
	Mean	19.0	.062	1.6	5.4	7.1
E4-8	2x11	20.9	.069	1.8	5.2	7.0
	2x13	20.6	.069	1.7	5.5	7.2
	2x17	20.8	.067	1.6	5.5	7.1
	Mean	20.8	.068	1.7	5.4	7.1
E12-1	3x10	17.8	.063	1.6	5.0	6.6
	3x12	19.1	.057	1.6	5.1	6.7
	3x14	21.0	.077	1.9	4.8	6.7
	3x16	23.6	.083	1.8	5.2	7.0
	3x18	18.2	.063	1.4	5.0	6.4
	Mean	19.9	.069	1.7	5.0	6.7
E12-14	4x10	17.1	.054	1.4	4.9	6.3
	4x11	19.2	.068	1.8	4.4	6.2
	4x13	20.8	.068	1.8	4.8	6.6
	4x15	19.9	.068	1.6	5.4	7.0
	4x17	18.9	.060	1.6	4.6	6.2
	Mean	19.2	.064	1.6	4.8	6.5
E15-2	5x10	20.1	.064	1.8	4.9	6.7
	5x11	21.1	.071	1.8	5.0	6.8
	5x12	19.8	.068	1.7	5.3	7.0
	5x14	20.7	.074	1.6	5.3	6.9
	5x16	22.1	.070	1.7	5.4	7.1
	5x18	19.1	.062	1.6	4.8	6.4
	Mean	20.5	.068	1.7	5.1	6.8
E15-15	6x11	20.7	.068	1.7	5.0	6.7
	6x13	21.7	.074	1.7	4.6	6.3
	6x15	21.1	.075	1.6	5.1	6.6
	6x17	21.5	.071	1.6	5.4	7.0
	Mean	21.2	.072	1.6	5.0	6.6

Table 36. (Continued)

Clone	Cross	Seed size ml/100 sds. x 100	Dry wt. g/sdlg. x 100	Radicle length mm	Hypocotyl length mm	R + H length mm
E20-14	7x10	19.0	.059	1.8	5.1	6.9
	7x12	19.5	.067	2.0	5.0	7.0
	7x13	20.1	.068	2.0	4.5	6.5
	7x14	21.6	.074	1.8	5.5	7.3
	7x16	24.4	.083	2.0	5.3	7.3
	Mean	20.9	.070	1.9	5.1	7.0
E20-15	8x11	22.4	.075	2.1	4.9	7.0
	8x13	23.6	.080	2.2	5.3	7.5
	8x14	21.2	.077	1.7	5.3	7.0
	8x15	21.6	.068	2.0	5.1	7.1
	8x17	23.8	.082	1.9	5.7	7.6
	Mean	22.5	.076	2.0	5.3	7.2
E20-21	9x14	22.4	.080	1.8	5.4	7.2
	9x16	26.1	.082	2.0	5.2	7.2
	Mean	24.2	.081	1.9	5.3	7.2
R6-8	10x1	16.8	.060	1.5	5.5	7.0
	10x3	17.8	.063	1.6	5.0	6.6
	10x4	17.1	.054	1.4	4.9	6.3
	10x5	20.1	.064	1.8	4.9	6.7
	10x7	19.0	.059	1.8	5.1	6.9
	Mean	18.2	.060	1.6	5.1	6.7
R6-18	11x2	20.9	.069	1.8	5.2	7.0
	11x4	19.2	.068	1.8	4.4	6.2
	11x5	21.1	.071	1.8	5.0	6.8
	11x6	20.7	.068	1.7	5.0	6.7
	11x8	22.4	.075	2.1	4.9	6.7
	Mean	20.9	.070	1.8	4.9	6.7
R9-5	12x3	19.1	.057	1.6	5.1	6.7
	12x5	19.8	.068	1.7	5.3	7.0
	12x7	19.5	.067	2.0	5.0	7.0
	Mean	19.5	.064	1.8	5.1	6.9

Table 36. (Continued)

Clone	Cross	Seed size ml/100 sds. x 100	Dry wt. g/sdlg. x 100	Radicle length mm	Hypocotyl length mm	R + H length mm
R10-6	13x2	20.6	.069	1.7	5.5	7.2
	13x4	20.8	.068	1.8	4.8	6.6
	13x6	21.7	.074	1.7	4.6	6.3
	13x7	20.1	.068	2.0	4.5	6.5
	13x8	23.6	.080	2.2	5.3	7.5
	Mean	21.4	.072	1.9	4.9	6.8
R10-9	14x1	19.7	.061	1.8	5.6	7.4
	14x3	21.0	.077	1.9	4.8	6.7
	14x5	20.7	.074	1.6	5.3	6.9
	14x7	21.6	.074	1.8	5.5	7.3
	14x8	21.2	.077	1.7	5.3	7.0
	14x9	22.4	.080	1.8	5.4	7.2
	Mean	21.1	.074	1.8	5.3	7.1
R10-12	15x4	19.9	.068	1.6	5.4	7.0
	15x6	21.1	.075	1.6	5.1	6.6
	15x8	21.6	.068	2.0	5.1	7.1
	Mean	20.9	.070	1.7	5.2	6.9
R14-5	16x1	21.8	.070	1.6	5.9	7.5
	16x3	23.6	.083	1.8	5.2	7.0
	16x5	22.1	.070	1.7	5.4	7.1
	16x7	24.4	.083	2.0	5.3	7.3
	16x9	26.1	.082	2.0	5.2	7.2
	Mean	23.6	.077	1.8	5.4	7.2
R14-7	17x2	20.8	.067	1.6	5.5	7.1
	17x4	18.9	.060	1.6	4.6	6.2
	17x6	21.5	.071	1.6	5.4	7.0
	17x8	23.8	.082	1.9	5.7	7.6
	Mean	21.2	.070	1.7	5.3	7.0
R22-3	18x1	17.9	.058	1.6	4.8	6.4
	18x3	18.2	.063	1.4	5.0	6.4
	18x5	19.1	.062	1.6	4.8	6.4
	Mean	18.4	.061	1.5	4.9	6.4

Table 36. (Continued)

Clone	Cross	Seed size ml/100 sds. x 100	Dry wt. g/sdlg. x 100	Radicle length mm	Hypocotyl length mm	R + H length mm
Check strains						
	Empire	14.4	.052	1.3	4.4	5.7
	E-1	17.6	.056	1.5	4.8	6.3
	Russian	18.4	.054	1.6	5.2	6.8
	Carroll	18.2	.064	1.6	4.9	6.5
Mean of checks		17.2	.056	1.5	4.8	6.3
L.S.D. (.05)		2.3	.018	0.5	0.8	0.8

heaviest seedlings. None of the seedlings from the Russian x Russian F_1 progenies were heavier than the check with the heaviest seedlings. Similar trends were observed for the other traits, i.e., the greatest proportion of high performing F_1 progenies coming from Empire x Empire crosses, followed by Empire x Russian crosses and the smallest proportion from Russian x Russian crosses.

Phenotypic correlation

Open-pollination seeds collected from F_1 progenies were used to study the relationship of seed size with progeny seedling vigor traits. Phenotypic correlations among seed size and progeny seedling vigor traits are shown in Table 37. Correlation coefficients were calculated from entry means. All coefficients were positive. Seed size was closely

Table 37. Phenotypic correlations among seed size and progeny seedling vigor traits

	Seedling dry weight	Radicle length	Hypocotyl length	R + H length
Seed size	0.87**[a]	0.71**	0.47**	0.72**
Seedling dry weight	--	0.66**	0.33**	0.59**
Radicle length		--	0.15	0.60**
Hypocotyl length			--	0.88**

[a]Degrees of freedom = 74.

**Significant at the .01 level of probability.

associated with seedling dry weight. The correlation between seed size and hypocotyl length was relatively low. Correlations among seedling traits were significant except for the one between radicle length and hypocotyl length.

DISCUSSION

The results obtained in this study are in general agreement with previous findings for other crops on the importance of genetic diversity in the expression of heterosis. Intersource crosses averaged higher in forage yield than intrasource crosses; however, they did not outyield crosses within the Russian source. The intersource crosses gave a yield increase of 12 and 16 percent in 1968 and 1969, respectively, over the intrasource crosses, or an average of 14 percent heterosis for the two-year period. These results, however, do not necessarily imply that the positive relationship between heterosis and genetic diversity will hold throughout the entire range of diversity in the species. It is widely accepted that cumulative differences between isolated populations may eventually become great enough to cause genic imbalance in population hybrids. Results of Moll et al. (1965) in corn revealed that heterosis increased with increasing divergence, but extremely divergent crosses resulted in a decrease in heterosis. Cress (1965) also pointed out that genetic diversity is necessary for significant heterosis but not sufficient to guarantee it. He showed that, with more than two alleles per locus, negative contributions to heterosis are to be expected at certain loci, and the net effect may be a hybrid genotypic value equal to or below the midparent.

Comparison of all two-clone combinations in the three hybrid groups with check strains showed that the greatest number of high yielding crosses were obtained from R x R, followed by E x R, and the least from E x E. Of 19, 18 and 39 two-clone combinations in E x E, R x R, and E x R, 0, 17 and 13 percent, respectively, exceeded the high check strain in first-year forage yield. Crosses within the Russian source performed equally well as crosses between sources. In intrasource crosses, Empire clones were relatively low and Russian clones relatively high in performance. Thus, the intersource crosses actually represented crosses between low and high yielding clones. Previous experience in corn has shown that the amount of heterosis displayed depends not only on genetic diversity but also on the combining ability of the parents. The work of Johnson and Hayes (1940) showed that single crosses between low combiners yielded lower, on the average, than single crosses of relatively high combining lines when the single crosses were made between inbreds of diverse genetic origin. Furthermore, they found that single crosses between low and high combining inbreds yielded as well as single crosses between high combiners.

Numerous investigators (Crow, 1952; Hull, 1952; Sprague et al., 1959; Penny et al., 1962; and others) have attempted to explain the type of gene action involved in heterosis in corn. No conclusive evidence has been obtained in favor of either the dominance or overdominance hypothesis. It is the present feeling that both types of gene action are operative.

There is substantial evidence that birdsfoot trefoil is an autotetraploid species (Dawson, 1941; Buzzell and Wilsie, 1963; Bubar and Miri, 1965). Determining quantitative gene action in autotetraploid organisms involves several complexities and difficulties in estimating genetic variance components (Samadi and Stanford, 1969). It was beyond the scope of this research to draw valid conclusions as to the type of gene action involved in heterosis.

Comparisons of Empire and Russian crosses revealed the superiority of R x R over E x E in forage yield, spring vigor, winterhardiness and seed production. One trait which contributed to the superiority of the R x R progenies was their winterhardiness. The winter of 1968-1969 was severe and a considerable number of plants were lost from the E x E progenies. The winterhardiness of the Russian material also has been reported by Bubar (1958) in Canada.

Superiority of F_1 progenies over parental check strains in first year forage yield, but not in second year yield, was attributed largely to seedling vigor. Observations indicated that F_1 progenies exhibited greater seedling vigor which probably enabled them to become established more rapidly than the check strains. This early advantage of the F_1's, as reflected in first year forage yield, disappeared in the second year.

Among the characters for which the clones were selected (forage yield, seed yield and seed size), selection for seed size was the most effective, particularly in the Empire group. Selection for forage yield and seed yield was not effective. Selection of parents in the Empire group resulted in a shift towards upright growth habit.

Increased variability within populations may be expected through hybridization. The structure of the population from which the parents are selected is important in this respect. It is expected that crosses between two divergent varieties will show more variability than crosses within varieties. Results of this study tended to support this statement particularly with regard to yield. Forage yield mean squares for intersource crosses were considerably larger than those for intrasource crosses. Similar results were obtained by Sriwatanapongse and Wilsie (1968) in alfalfa.

The relative importance of general and specific combining ability for a character is dependent upon the magnitude of variation among parents, whether or not the parents were selected for the character, and on the genetic system governing the character. Valid inferences on the relative importance of general and specific combining ability will emerge when a pattern develops from a series of experiments on a particular character. In the present study, the general combining ability variance was appreciably greater than that for specific combining ability for most traits. Essentially, these results are in agreement with those reported by Miller (1968). This suggests that general combining ability would be of considerably greater importance than specific combining ability in a selection program. The significant specific combining ability for yield in the two populations (E x E and R x R) indicates that the breeder should consider this source of variation also when selecting lines for forage yield. This situation might be different for other clones.

The clones used in this study differed considerably in genotype as indicated by the performance of their single cross progenies. In crosses within sources, the Russian clones R10-12 and R9-5 were excellent in total yield. R10-12 also was one of the best clones in pod set score. Generally, the performance of crosses among Empire clones was poor. The superiority of the Russian clones can be attributed partially to winterhardiness. In contrast to intrasource performance, some of the Empire clones performed well in combination with Russian clones. Three of the four highest yielding clones in intersource crosses were of Empire origin. One clone, E15-15, did extremely well in forage and seed production. At least one of the parents in the 16 highest yielding crosses was E15-15, R10-12, R10-6, E12-1, or R9-5.

Data from full-sib progenies indicated that the effects of inbreeding in birdsfoot trefoil were, in general, similar to those found in other cross-pollinated crops. Yield comparisons between F_1 and full-sib progenies through a common check revealed a decrease in yield of about 8 percent in the full-sib progenies. The intrasource crosses showed greater inbreeding depression than the intersource crosses. Since heterosis is the converse of inbreeding depression, it is expected that those crosses showing greater heterotic response should also show greater inbreeding depression. The reason for the deviation of the observed results from the expected is not obvious. However, evaluation of the two populations in different years may have been a factor.

In small-seeded forages, the ability of the seedling to emerge, to compete with other plants, and to establish itself is often a factor in determining the vigor and density of a stand. Among legumes, birdsfoot trefoil is seriously deficient in this ability. In trefoil, Henson and Tayman (1961) were among the first to report a positive relationship between seed size and weight of seedling shoot and root. Draper and Wilsie (1965), by three cycles of recurrent selection, increased the seed size of Viking and Empire trefoil lines by 60 percent and 20 percent, respectively. Twamley (1967) investigated the extent to which seed size could be used in a breeding program to screen out lines of poor seedling vigor in the erect or hay-type trefoil. He concluded that no serious loss of superior germplasm would result if 80 percent of the lines were discarded on the basis of seed size. In the present study, the objectives were to study the effect of hybridization within and between Empire and Russian germplasm sources on seed size and progeny seedling vigor traits, and to determine the relationship of seed size with seedling vigor. The clones used in this study were selected for large seed size. It must be pointed out that open-pollination seeds of F_1 progenies were used. Data indicated that seedling vigor, as measured by dry weight, hypocotyl length and radicle length, was largely a function of seed size just as had been reported by Henson and Tayman (1961), Stickler and Wassom (1963) and others. In contrast to the performance for forage yield, Empire x Empire crosses produced a greater number of large seeded F_1 progenies than either Russian x Russian or Russian x Empire crosses. Similar results were obtained for progeny seedling traits, since seedling vigor was largely a function of seed size. Heterosis was found for hypocotyl and total seedling length, but not for seed size, radicle length and dry weight in crosses between sources. From the standpoint of competition for light, a longer hypocotyl length or stem length is desirable.

General combining ability variance was of considerably greater importance than specific combining ability for all seed and seedling traits. Draper and Wilsie (1965) reported similar findings for seed size. Again, caution should be exercised in drawing conclusions from a single experiment.

Considerable emphasis has been placed on breeding trefoil for improved forage yield, seed size and seed yield. A knowledge of interrelationships among characters that affect these important traits is necessary if selection for their simultaneous improvement is to be effective. Correlation analysis indicated that, considering any pair of traits, the magnitude of the coefficient varied considerably from F_1 to full-sib progenies. Such variation emphasized the need for caution in formulating general conclusions from correlation studies. Genotype, method of planting, and season of evaluation can be expected to influence the degree of relationship between characters. In this study, forage yield was closely associated with spring vigor and winterhardiness. It also was correlated with prostrate growth habit, which in turn, was associated with winterhardiness. In the spaced plantings used in this study, the least hardy plants were generally erect and nonspreading, while hardy plants were generally decumbent and spreading in growth habit. Similar results were obtained in alfalfa by Blinn (1911), Smith (1961) and Larson and Smith (1963). Miller (1968) found a lack of association between the two traits in trefoil, which apparently was due to the absence of variability in growth habit in his materials.

A positive association between seed yield and forage yield, similar to that reported by Hulewicz (1961) for trefoil and Liang and Riedl (1964) for alfalfa, was obtained in this study. Hulewicz suggested that the greater number of pod bearing stems on the more vigorous plants in his material may have contributed to this positive relationship. Liang and Riedl were of the opinion that, of the two components of forage yield, plant height is more important than stem number in conditioning seed yield. It is the writer's observation that the number of flower bearing stems plays a more important role than plant height in influencing seed yield in birdsfoot trefoil. Seed size was weakly associated with forage yield. These results suggest the possibility of simultaneous improvement of these three characters. The performance of crosses between sources lends support to this statement. Progenies of crosses between Empire and Russian clones appeared to inherit the high forage yield of the Russian parents (Table 9) and the greater seedling vigor of the Empire parents (Table 27).

SUMMARY AND CONCLUSIONS

Clones derived from two diverse sources of birdsfoot trefoil, Empire and two Russian introductions, were used as parent materials in this study. Nine selected clones from each source were crossed in a partial diallel fashion, both within and between sources, to evaluate the influence of degree of genetic diversity on the expression of heterosis, to determine the effects of intra- and intersource hybridization on seed size and progeny seedling vigor, to study general and specific combining ability of the parent clones, to study the interrelationships among characters that affect forage yield, seed size and seed load, and to select clones with good combining ability for inclusion in a recurrent selection program. Sibmating was practiced in 16 F_1 progenies to study the breeding behavior in the second generation.

Crosses of more distantly related parents showed heterosis for forage yield when they were compared with crosses of more closely related parents. The intersource crosses gave an average yield increase of 14 percent over intrasource crosses.

General combining ability mean squares were considerably greater than specific combining ability mean squares for most traits, indicating the importance of additive genetic variance. Specific combining ability mean squares for forage yield were significant in two populations, suggesting that the breeder should consider this source of variation also when breeding for high forage yield.

Correlation analysis indicated that considerable variation between F_1 and full-sib progenies often existed in the degree of correlation between a pair of characters. In general, the magnitude of the coefficients and the frequency of significance increased as the population became inbred. Certain characters were associated closely among both types of progenies. Forage yield was closely correlated with spring vigor and winter-hardiness, but poorly correlated with seed size. High yield also showed a tendency to be associated with a more prostrate growth habit and good pod production. Seed size was independent of seed load. The associations among forage yield, seed load and seed size suggest the possibility of simultaneous improvement of these three important traits.

Seed size and progeny seedling vigor studies revealed that seedling vigor, as measured by dry weight, hypocotyl length and radicle length, was largely a function of seed size. On the average, crosses between sources were superior in hypocotyl and total seedling length to crosses within sources. General combining ability was of considerably greater importance than specific combining ability for seed size and seedling vigor traits, indicating the importance of additive genetic variance.

Sib-mating for one generation resulted in decreased vegetative vigor. Intrasource crosses manifested greater inbreeding depression than the intersource crosses.

The 18 clones used in this study differed considerably in genotype as indicated by the performance of their single cross progenies. In intrasource crosses, the best performing clones were: R10-12 and R9-5 for forage yield; R10-12, R14-5 and R6-8 for pod production; and E20-21 and E20-15 for seed size. In intersource crosses, the best performing clones were: E15-15, R9-5, E12-14 and E12-1 for forage yield; E20-14, E12-14, R10-9, E15-15 and E4-1 for pod production; and E20-21 and R14-5 for seed size. At least one of the parents in the 16 F_1 crosses highest in forage yield was E15-15, R10-12, R10-6, E12-1, or R9-5.

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