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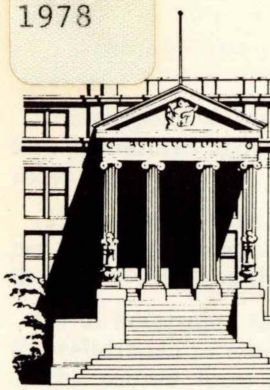
1978

CODEN: IWRBBR (585) 909-932 (1978)
US ISSN: 0021-0692



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Selection Procedures in the Development of Maize Inbred Lines and the Effects of Plant Densities on the Relationships Between Inbred Traits and Hybrid Yields

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Research Bulletin 585. . .September 1978. . .Ames, Iowa

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CONTENTS

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SUMMARY

The purpose of this research was to use five selection procedures to develop inbred lines of maize *(Zea mays L.)*:

(1) to compare the selected lines for performance *per se* and in testcrosses at various plant densities, thereby evaluating the selection procedures; and

(2) to determine the effects of plant densities on the relationships among plant, ear, and grain traits of the inbred lines and between these traits and hybrid yield performance.

The source population was an Iowa Synthetic, BS1. Five groups of lines were obtained: Group 1, selected visually at a density of 59,000 plants/ha in rows spaced 102 cm; Group 2, selected visually and for one ear per plant at a density of 29,500 plants/ha in rows spaced 102 cm; Group 3, selected visually and for two ears per plant at a density of 29,500 plants/ha in rows spaced 102 cm; Group 4, selected visually at a density of 59,000 plants/ha in rows spaced 51 cm; Group 5, selected for testcross performance (double-cross tester) at 59,000 plants/ha in rows spaced 51 cm. Lines in groups 1 to 4 were selected in the S_0 to S_4 generations and lines in Group 5 in the S_0 to S_2 generations with some visual selection of the lines and plants when the testcrosses were produced. Nineteen lines in each of groups 1 to 4 and a control (BS1) were evaluated in testcrosses (double-cross tester) in eight environments, three plant densities per environment (Experiment I). Also, the lines in groups 1 to 4, 10 lines in Group 5, and the control were evaluated in testcrosses (double-cross tester) in two environments, 51-cm row width and 59,000 plants/ha (Experiment II).

Average yields (q/ha) of the groups and control in Experiment I were: Group 1, 63.1; Group 2, 62.6; Group 3, 65.1; Group 4, 63.9; Control, 62.6. There were no significant differences among group yields averaged over all densities and environments, and the average of the groups was not different from the control. Group 3 had less barrenness and more root and stalk lodging than the other groups. In Experiment II, average yields (q/ha) of the groups and control were: Group 1, 89.9; Group 2, 86.0; Group 3, 92.4; Group 4, 91.2; Group 5, 90.9; Control, 89.7. None of the groups yielded significantly different from the control. Group 3 yielded significantly higher than groups 1 and 2, and Group 2 yielded significantly less than all other groups. It was concluded that visual selection was just as effective as early testing in the development of inbred lines.

The inbred lines in groups 1 to 4 were evaluated at one location for 2 years and two plant densities, 29,500 and 59,000 plants/ha. Data were obtained for 13 plant, ear, and grain traits. The average yields were higher at the high density in both years, with the average of the 2 years being 40.2 q/ha (high density) and 29.5 q/ha (low density). Differences among groups were highly significant for all traits except leaf area and grain yield.

There were no strong relationships between inbred plant traits and inbred yields, except delay in silk emergence, which caused barrenness and, thereby, decreased yields. Ear length was the most important component of yield; r= 0.56** in the low density and 0.69** in the high density. Generally, plant densities had no consistent effects on the relationships among the inbred traits except that, between yield and yield components, the r-values increased from the low to high density for all traits except ears per plant.

Correlation coefficients for inbred traits with testcross yields showed that the inbred plant traits had little predictive value for testcross yields. Plant densities had no consistent effects, except that the r-value for leaf area with testcross yields decreased from the lower to the higher densities of the inbreds and testcrosses in Experiment I. Ear length, weight/300 kernels, and inbred yield had the highest predictive values for testcross yields, the highest r-values being 0.45** for inbred yields in Experiment I and 0.48** for kernel weight in Experiment II. Generally, r-values for inbred ear and grain traits with testcross yields increased for higher densities.

The highest multiple correlation coefficients (R) were obtained for testcross yields with 13 inbred traits, R = 0.64**, in high density of the inbreds and highest density of the testcrosses in Experiment I and R = 0.66** for high inbred density in Experiment II. The R values of testcross yields with seven ear and grain traits were almost as high as for all inbred traits. Generally, R values for testcross yields with the ear and grain traits increased with the higher densities, whereas, for testcross yields with plant traits, they decreased with higher densities.

Generally, the results favor the development of inbred lines in a high plant density or of two-eared lines in a low plant density as opposed to single-eared types in a low plant density. Selection for two-eared lines may have problems with root and stalk lodging. No advantage was observed for inbred lines developed in closely spaced rows.

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Selection Procedures in the Development of Maize Inbred Lines and the Effects of Plant Densities on the Relationships Between Inbred Traits and Hybrid Yields[1]

W. A. Russell[2] and Veronica Machado[3]

The development of hybrids in maize *(Zea mays* L.) breeding programs has been based on the selection and evaluation of inbred lines for more than 50 years. Shull (1909) outlined the pure-line method for maize breeding, and the basic procedure is still the same in most programs. Every maize breeder has certain unique procedures, but the final objective is to develop inbred lines that have superior hybrid performance. Breeders still are searching for better procedures that will permit the identification of inbred genotypes with the genetic potential to contribute superior yield performance to hybrids. If the breeder had such procedures, the opportunities to obtain superior hybrids would be enhanced for the same input of resources.

There are two primary systems relative to inbred development in a hybrid maize breeding program. One system relies on visual selection among and within ear-to-row progenies for several inbreeding generations before hybrid evaluation. Testing for combining ability may be delayed to about the fifth generation of inbreeding when the number of selected lines is relatively small. Various selection procedures may be applied to assist in the isolation of inbred lines with resistance to important diseases and insects, maturity for certain areas of adaptation, plant canopy type, ear size, and grain quality. All these traits are heritable and are deemed necessary in hybrids. An assumption in this breeding system is that there are some favorable relationships between certain plant, ear, and grain traits in parent lines and combining ability for yield; thus, selected lines should be better for hybrid yields than a random set of lines from the same source. Several studies correlating traits of inbred lines and yields of their hybrid progenies were reported in the earlier years of hybrid corn (Kiesselbach, 1922; Richey, 1924; Richey and Mayer, 1925; Hayes, 1926; Nilsson-Leissner, 1927; and Jorgensen and Brewbaker, 1927). Two of the most comprehensive studies for using inbred characters to predict hybrid performance were reported by Jenkins (1929) and Hayes and Johnson (1939). Although these earlier studies generally showed positive correlations between plant-vigor traits and hybrid yields, in most instances, the r-values were too small to be of much predictive value. Hayes and Johnson (1939), using 12 inbred traits with topcross yields, obtained a multiple correlation of $R = 0.666$. Some of the earlier studies used relatively few lines, and, frequently, the lines were a selected sample. More recently, Gama and Hallauer (1977) used 160 random inbred lines from Iowa Stiff Stalk Synthetic and 320 single-cross hybrids. In two procedures of pairing between inbreds and hybrids to calculate correlation coefficients, they obtained only one significant r-value between inbred traits and hybrid yields, and it was too small to be of predictive value.

A second system of inbred development is based on evaluations for combining ability in the early generations of inbred development. Genotypes identified for above-average hybrid performance in this early testing procedure become the progenies used for inbred development. Jenkins (1935) proposed the early testing procedure; Sprague (1946), Lonnquist (1950), and Russell and Teich (1967) presented data that support the procedure. Russell and Teich (1967) also found that visual selection of the inbred lines in high plant density was just as effective as the early testing procedure in the identification of lines with above-average hybrid yield performance. Russell (1969) observed that early testing was effective if the selected lines were used in combination with the tester used in the development of the lines. The gain was not evident when these lines were evaluated in hybrid combination with a different tester.

Probably, most breeders use a system somewhat intermediate between the two procedures. Preliminary evaluation for hybrid performance may begin about the third generation of inbreeding. Thus, when the initial hybrid testing is being conducted, the breeder will also do some visual selection among and within the inbred progenies *per se.* More extensive hybrid evaluation, with more testers, will be conducted when lines have been identified that seem to have potential for use in hybrid seed production programs.

With the advent of the single-cross hybrid as the predominant type, the performance of the parent in-

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bred lines *per se* has assumed major importance. The inbred line must be one that the commercial seed producer can use profitably either as a female or a male parent; otherwise, it will not be used regardless of its superiority in hybrids.

Maize breeders have recognized variation among inbred genotypes for response in hybrids to plant densities. It is known that certain lines have good hybrid performance at low plant densities, but, at high plant densities, they do not perform as well because of barrenness. Russell and Teich (1967) showed that inbred lines that did not resist barrenness contributed to barrenness in hybrids. Russell (1968) and Prior and Russell (1975) showed that lines with the genetic potential to develop two ears per plant gave more resistance to barrenness in hybrids than did single-eared types. Geadelmann and Peterson (1976) reported that selections improved for ears per plant averaged a 10% increase in topcross yield, whereas selections improved for ear length and kernel depth had an average topcross increase of 5 and 0%, respectively. The results of some studies (El-Lakany and Russell, 1971a; Russell and Teich, 1967; Prior and Russell, 1975) suggest that high correlations of parent-line characteristics with hybrid performance may be obtained when the materials are grown in stress environments such as high plant densities. Most early studies relating performance of inbred parents with hybrid performance were conducted at relatively low plant densities and at fertility levels not relevant to current maize culture.

The purpose of this research was to use five selection procedures to develop inbred lines to be used as follows: (1) to compare the selected lines for performance *per se* and in testcrosses at various plant densities, thereby evaluating the selection procedures, and (2) to determine the effects of plant densities on the relationships among plant, ear, and grain traits of the inbred lines and between those inbred traits and hybrid yield performance. The hypothesis was that higher plant densities, which subject the individual plant to greater stress environment, may cause stronger relationships between inbred traits and testcross yields.

MATERIALS AND METHODS

Derivation of experimental materials

The source population was a maize synthetic, BS1, obtained by crossing Iowa Two-Ear Synthetic #1 C2 and Iowa Corn Borer Synthetic #3 and random mating for two generations. Iowa Two-Ear Synthetic #1 is a 10-inbred line synthetic, and Iowa Corn Borer Synthetic #3 is a 16-inbred line synthetic; consequently, BS1 is a broad genetic base population. BS1 has favorable gene frequencies for such desirable attributes as leaf-feeding resistance to first-brood European corn borer (*Ostrinia nubilalis,* Hübner), resistance to leaf diseases commonly occuring in Iowa, resistance to stalk rot, and prolificacy. Also, Hallauer and Sears (1968) reported that both the component synthetics used to develop BS1 had positive general combining ability effects for yield.

In the S_0 generation, approximately 1200 plants were self pollinated. Selection for healthy plants and plant and ear types of the S_0 plants at harvest, and among S_1 lines for resistance to leaf feeding by the European corn borer, reduced the number of S_1 lines to 259. In 1968, these S_1 lines were planted in three separate nurseries as follows: density of 59,000 plants/ha (i.e., 50 plants per progeny in single-row plots spaced 102 cm between rows), density of 29,500 plants/ha (i.e., 25 plants per progeny in single-row plots spaced 102 cm between rows), and density of 59,000 plants/ha (i.e., 32 plants per progeny in two-row plots spaced 51 cm between rows and plots). In the first nursery, we used two-plant hills spaced 34 cm, and only plants in two-plant hills that had one or two plants in adjacent hills were eligible for selection. In the second nursery, we used single-plant hills, and any plant was eligible for selection. In the third nursery, we used single-plant hills, but only plants that were bordered by plants were eligible for selection.

For four generations, S_1 to S_4, visual selection was performed among and within progenies for vigorous plant type, simultaneous pollen dehiscence and silk emergence, healthy plants, and desirable ear type with high seed yield. Stalk inoculation with a *Diplodia* spore suspension was made soon after pollination in all selfed plants so that stalk-rot-resistant plants could be selected at harvest. During the S_2 to S_4 generations in a nursery separate from the breeding nursery, the lines were evaluated for resistance to leaf feeding by the first-brood European corn borer. Artificial infestations of the insect were used. Several pollinations were made per selected progeny in each generation, but usually no more than two selfed ears were saved at harvest. In the S_1 generation, selections for 1- and 2-eared plants were made in the low-density nursery, and in subsequent generations, these were handled as two separate groups, and selection was continued for the 1-eared and 2-eared types, respectively. Selections were grown ear-to-row in each generation, and in the successive generations, usually only one selection of the same family was saved.

In 1972, all S_5 progenies were grown in ear-to-row plots at a density of 29,000 plants/ha. Self-pollinations were made of most plants to obtain seed for further studies. A few additional lines were discarded because of undesirable agronomic characteristics. For each selected family (one or two S_5 progenies), seed of all self-pollinated ears was bulked. Also, these S_5 families were grown in a crossing nursery to produce testcrosses with double-cross Ia5724. At this time, the two-eared group had 19 lines; therefore, the number of testcrosses in each of the other groups was arbitrarily reduced to 19.

Another group of lines was developed from BS1, for which the basis of selection was testcross performance at 59,000 plants/ha in replicated plots with rows spaced 51 cm. In the S_0 generation, 156 plants were self-pollinated, and each was crossed with five or six plants of Ia5724. Selection among the S_0 plants at harvest, as described previously for the visual selection program, reduced the number to 100. Selection among testcrosses of the S_0, S_1, and S_2 generations and visual selection within the S_1 and S_2 progenies when testcrosses were produced reduced the number of lines to 10 for the S_3 generation.The average testcross yield of these 10 selected S_3 lines in testcrosses was 7.9 q/ha greater than that of BS1 x Ia5724, and this difference was highly significant. These lines also were crossed to Ia5724.

To simplify the presentation, the lines will be designated as follows:

Group 1, lines selected for phenotype at a density of 59,000 plants/ha and rows spaced 102 cm;

Group 2, lines selected for phenotype (one ear per plant) at a density of 29,500 plants/ha and rows spaced 102 cm:

Group 3, lines selected for phenotype (two ears per plant) at a density of 29,500 plants/ha and rows spaced 102 cm;

Group 4, lines selected for phenotype at a density of 59,000 plants/ha and rows spaced 51 cm;

Group 5, lines selected on the basis of testcross performance (Ia5724 as tester).

Evaluation of selected inbred lines for testcross performance

In one set of evaluations, Experiment I, testcrosses of lines in groups 1 through 4 were evaluated in eight environments, with two replications and three plant densities in each environment. The environments were four locations in 1974, three locations in 1975, and one location in 1976. (An additional location had been planted in each of 1975 and 1976, but these tests were not harvested because of extreme drought effects.) There were 19 testcrosses in each group; thus, with five entries of BS1 x Ia5724, each experiment had 81 entries. We used two-row plots, with 518-cm row length and rows spaced 76 cm in six experiments and 96 cm in two experiments. A split-plot design was used in which densities were randomized into three main plots of a replication and testcrosses were randomized as the subplots of a density. Within each main plot, we used a 9 x 9 simple lattice. All experiments were planted by a two-row, cone-type mechanical planter. The plant densities after thinning were equivalent to 39,000, 54,000, and 69,000 plants/ha. All experiments were planted on soils with high productive capacity supplemented by fertility programs based on soil tests. The experiments at the Agronomy Research Center in 1974, 1975, and 1976 were side dressed at a rate of approximately 50 kg/ha of N the third week of June.

Data obtained for each plot at harvest were: number of plants, number of root- and stalk-lodged plants, number of dropped ears, number of barren plants at the two higher densities, grain weight, and percentage grain moisture. All plots were harvested with a two-row combine adapted for small-plot work. At harvest, there was no gleaning for ears lost because of lodging or dropping.

In a second set of evaluations, Experiment II, testcrosses of lines in groups 1 to 5 and four entries of BS1 x Ia5724 were compared in a 9 x 10 triple rectangular lattice in two trials, one location in each of 1974 and 1975. Plots were hand-planted to a plant density equivalent to 59,000 plants/ha after thinning. The plot size was four rows, 508 cm long and rows spaced 51 cm. Fertility level was high in both seasons, and all plots were side dressed with approximately 50 kg/ha of N the third week of June.

Data recorded for each plot were the same as for Experiment I. The plots were hand-harvested but shelled by the two-row combine to obtain grain weights and a sample for moisture determination. All ears were saved; thus, total yields were recorded for each plot.

Statistical procedures for testcross data

Grain yields were converted to q/ha at 15.5% moisture. Lodging and barren-plant counts were converted to percentages of plants per plot. (Dropped-ear data were not used because of a large number of zero values.) In Experiment I, the simple lattice analysis was used for each density in a test, and entry means were adjusted for block differences. Then, for each test, the three simple lattices were combined as a split-plot test, with plant densities as the main plots and entries as the subplots. Replications, densities, and entries were considered fixed variables; locations and years were equated to eight random environments. For each environment, the error degrees of freedom and effective error mean squares were obtained by pooling the appropriate values for each density. A combined analysis for entries and densities over all environments was calculated by using the entry means for each density in an environment. The pooled error mean square was obtained as just described.

In the combined analysis of variance, the degrees of freedom and sums of squares for entries and first-order interactions involving entries were partitioned into orthogonal comparisons based on the groups of testcrosses. The three plant densities were equally spaced, independent variables. For the yield data, degrees of freedom and sums of squares for densities and first-order interactions involving densities were partitioned into linear and quadratic components. To calculate F-tests, the pooled error mean squares were used to test entries x environments and entries x densities x environments. Entries and orthogonal components in entries were tested by entries x environments and appropriate orthogonal components in the interaction. Entries x densities and the linear and quadratic components were tested by the mean square for entries x densities x environments, or by the pooled error if the second-order interaction was not significant. Heterogeneity of error variances was detected among densities in individual trials and among environments. This was expected because of previous experiences with similar evaluations involving densities and environments (Russell and Teich, 1967; Prior and Russell, 1975). Consequently, the tests of significance may not be at the exact probabilities given.

Analyses of variance were made also for each density over eight environments. Orthogonal comparisons were obtained as explained previously. These analyses allowed comparisons of statistical parameters obtained in each of the three densities.

In Experiment II, each trial was analyzed according to the triple rectangular lattice procedures, and entry means were adjusted for block differences. A combined analysis for the two environments and orthogonal comparisons for entries and entries x environments were obtained similarly to the procedure described for Experiment I.

Evaluations of the selected inbred lines

The inbred lines in groups 1 to 4 were evaluated in experiments grown at the Agronomy Research Center in 1975-76. Each experiment included 76 inbred lines, plus five more lines to give a 9 x 9 triple lattice design. (Group 5 was not included because these lines had less inbreeding than the lines in groups 1 to 4.) Each experiment had two plant densities. A split-plot design was used in which densities were randomized into two main plots of a replication and lines were randomized as subplots of a density. Within each main plot, we used the 9 x 9 lattice randomization. We used single-row plots with 16 hills per row and rows spaced 102 cm in 1975 and 76 cm in 1976. Planting was with hand planters. Thinning to one or two plants per hill gave densities equivalent to 29,500 and 59,000 plants/ha for densities 1 and 2.

Data were obtained for 12 plant, ear, and grain characters in each plot. Measurements for plant height, ear height, ear row number, ear diameter, ear length, kernel depth, ears per plant, and grain yield were taken on 10 competitive plants per plot. In the higher density, data were obtained only in two-plant hills that had at least one plant in each adjacent hill. Plant height was taken to the collar of the top leaf, and ear height to the top ear node. Ear row number and diameter were taken only on the top ears harvested, and the average per plant was based on the number of ears used. Ear length was taken as the total length of all harvested ears (primary and secondary) for 10 competitive plants; a barren plant would be included as zero length. Kernel depth was obtained as the difference between ear and cob diameter and dividing by two. Ears per plant was based on the total number of ears harvested from 10 plants. Grain yield was for all ears harvested per plot and was converted to q/ha. Days to pollen shed and silk emergence were the number of days from July 1 when 50% of the plants had reached tassel shedding and silk emergence. Silk delay, obtained only for inbred means, was the interval in days between pollen shed and silk emergence. Leaf area was obtained by measuring the length and width of the third leaf above the top ear node for three plants per plot and was calculated on the mean cross product for the three leaves with no correction for shape. Weight per 300 kernels was taken for a sample in each plot. All ear and grain data were recorded after the ears had been dried to a uniform moisture level.

Statistical procedures for inbred line data

An analysis of variance was made for each character except silk delay, which was obtained only for the mean values of each density. The analysis procedures were essentially the same as already described for the testcrosses, except that the design was a triple lattice. In the combined analysis, for the F-tests involving comparisons among groups, the mean squares for entries x years and entries x densities x years were used as the denominator because of the low number of degrees of freedom for the orthogonal comparisons in these first- and second-order interactions.

Correlation analyses

Simple correlation coefficients were calculated among all 13 traits of the 76 inbred lines and between each of the 13 traits and yields of the testcrosses. Because one purpose of the research was to determine the effect of plant densities on relationships among traits of the inbred lines and between inbred traits and hybrid yields, simple correlations were calculated for each density of the inbreds and for all density combinations of the inbreds and hybrids.

Multiple correlation coefficients were calculated for inbred traits with hybrid yields. The R-values were calculated for each density of the inbreds with each density of the hybrids in Experiment I and with the one density in Experiment II. Five R-values were calculated in each case as follows:

(1) yields of the hybrids with all inbred traits;

(2) yields of the hybrids with all inbred plant traits;

(3) yields of the hybrids with all inbred ear and grain traits;

(4) yields of the hybrids with all inbred ear and grain traits except yield;

(5) yield of the hybrids with ear length, weight per 300 kernels, and inbred yield.

In the fifth R-value, these were the inbred traits that had the highest simple correlations with hybrid yields.

RESULTS

Four successive generations of inbreeding and selection reduced the original 259 S_1 lines to 92 lines in the four groups. The main traits selected against were: poor plant vigor; failure to have simultaneous silk emergence and pollen dehiscence, particularly in groups 1 and 4; excessive plant and ear height; undesirable ear traits such as poor seed set, low yield, and grain quality; failure to have good size of second ears in Group 3; root lodging; and poor stalk rot resistance, particularly in Group 3. Selections that had good development of two ears per plant in Group 3 frequently had poor stalk quality. No artificial epiphytotics for leaf diseases were used, but there was selection for resistance to leaf diseases when natural infection occurred.

Tests of individual testcrosses

Average grain yields over all entries for each plant density in the individual environments for Experiment I are shown in Table 1. The range of yields may be attributed primarily to rainfall quantity and distribution. None of the sites had rainfall quantity and distribution conducive to high yields at the highest density. Root lodging at Agronomy Farm and Martinsburg in late August 1975, followed by considerable plant deterioration before harvest, caused harvest losses, particularly in the highest plant density. The highest density, averaged over all environments, had a significant yield decrease from the low and intermediate densities.

The highest average yields were in Experiment II that had rows spaced 51 cm — 84.0 and 96.0 q/ha in 1974 and 1975. Some reasons for the higher yields in Experiment II may be: better plant distributions in the row with hand planting, plant spacing utilizing sunlight more efficiently, and no harvest losses. In both years, there were fewer barren plants in Experiment II than in either the intermediate or high density in Experiment I at the same location.

Table 1. Grain yields for three plant densities in eight environments, Experiment I.

Location and year	Yield at plant density/ha 39000	54000	69000	Mean
	q/ha			
1974				
Newell	52.5	50.8	48.1	50.5
Agronomy‡	74.5	79.9	76.3	76.9
Ames	53.2	53.2	49.8	52.0
Martinsburg	67.6	66.7	65.1	66.5
1975				
Newell	73.7	74.6	64.2	70.8
Agronomy‡	83.3	79.4	74.8	79.2
Martinsburg	64.3	60.5	55.6	60.1
1976				
Agronomy‡	53.7	55.9	48.8	52.8
Mean	65.2	65.1	60.0	63.4

‡Agronomy Research Center

Data are given in Table 2 for yield and other agronomic traits for testcrosses of groups 1 to 4 and control in Experiment I, averaged over all densities and environments. Results are summarized in Table 3 of the combined analyses of variance for entries, densities, and environments, with orthogonal comparisons for entries and extries x environments. The pooled error mean squares for yield (71.14) gives a C.V. = 13.3%, which is higher than desired. The relatively high C.V. was caused partly by the relatively low mean yield; however, the error mean square probably was inflated because of variable harvest losses caused by root and stalk lodging. Much of the inflation of the pooled error mean squares was caused by the high experimental errors for the 1975 Agronomy Farm experiment, which had the greatest incidences of root and stalk lodging.

Table 2. Agronomic data for testcrosses of four groups of inbred selections and the control averaged for three plant densities and eight environments, Experiment I.

Material	Yield q/ha	b_1§	Moisture %	Lodged Root %	Lodged Stalk %	Barren‡ plants %
Group 1	63.1	-2.78	22.7	10.5	11.2	13.6
Group 2	62.6	-2.73	22.7	8.8	10.8	14.0
Group 3	65.1	-2.13	22.4	12.7	13.7	9.2
Group 4	63.9	-2.39	23.1	8.9	11.5	12.9
Control	62.6	-3.08	23.6	10.6	13.6	12.8
S.E.	1.19	N.S.	0.17	0.71	1.02	1.14

‡Average for the two higher densities.

§Linear regression coefficients for yield regressed on densities.

Table 3. Analyses of variance for grain yield and four agronomic traits of testcrosses of four groups of selections and the control for data obtained in three plant densities and eight environments, Experiment I.

	D.F.	Mean squares: Yield	Moisture	Lodged: Root	Lodged: Stalk	Barren plants‡
Entries	80	809.78**	84.09**	1108.79**	784.16**	527.89**
1, 2, 3, 4 vs Control	1	245.94	161.95**	26.82	774.81	25.50
Among Groups 1-4	3	1153.86†	73.06**	3072.92**	1511.47**	2966.08**
Within Group 1	18	1051.97**	80.52**	928.59**	908.69**	376.70**
Within Group 2	18	706.54**	106.68**	1059.44**	779.91**	611.58**
Within Group 3	18	734.68**	67.24**	1574.32**	579.74**	78.76*
Within Group 4	18	885.29**	97.71**	844.91**	906.70**	778.51**
Within Control	4	65.58	1.81	26.46	68.15	21.89
Entries x environments	560	175.14**	5.86**	166.30**	179.74**	88.27**
1, 2, 3, 4 vs Control x Env.	7	148.76*	8.87**	84.96	148.38**	57.28
Among Groups 1-4 x Env.	21	501.25**	7.70**	165.46**	354.46**	318.48**
Within Group 1 x Env.	126	191.71**	6.90**	197.09**	200.57**	103.55**
Within Group 2 x Env.	126	152.85**	7.17**	161.38**	162.17**	85.32**
Within Group 3 x Env.	126	158.01**	4.19**	190.67**	185.08**	38.09
Within Group 4 x Env.	126	169.53**	5.21**	145.59**	168.03**	101.61**
Within Control x Env.	28	65.11	3.63	54.34	70.42	33.61
Entries x densities	160	90.56	2.85	58.95	105.92**	69.55**
Entries x environments x densities	1120	81.67*	2.43	70.05	64.25	39.46
Pooled error	1632	71.14	2.32	64.50	59.05	38.18

†, *, **Significant at the 10%, 5%, and 1% levels.

‡ only 2 densities; D.F. = 80 for entries x densities, 560 for entries x environments x densities and 1136 for pooled error.

Differences among all entries were highly significant for all traits; also, the entries x environments interactions were all highly significant, but with the mean squares being of much lower magnitude than for the main effects of entries. Much of the total variation among entries was caused by the differences within each of the four groups. A similar situation also existed for the interaction with environments, although, for barren plants in Group 3, the interaction was not significant. Differences between the control and the average of groups 1 to 4 were not significant, except for grain moisture. Testcrosses of the selections averaged lower harvest moisture than did the control. Although the testcrosses of selected lines averaged 1.2 q/ha more than the control over all densities and environments, this difference was not significant because of the significant mean squares for groups 1 to 4 vs. control x environments. Differences among groups 1 to 4 were highly significant for all traits except yield, and the interaction among groups with environments was highly significant for all traits; the variation among groups 1 to 4 was significant for yield at the 10% probability level. Group 3 had the highest average yield, mainly because the yields of this group, relative to groups 1, 2, and 4, were much greater in the drought-stress environments at Newell in 1974 and at the Agronomy Farm in 1976. In the experiments that had excessive root and stalk lodging (i.e., Agronomy Farm and Martinsburg in 1975), yields for Group 3 were less than for some of the other groups. Because Group 3 had more root and stalk lodging, harvest losses were greater for this group. The lower incidence of barren stalks for Group 3 (Table 2) is evident. The superiority of Group 3 for this trait was more pronounced in Density 3 than in Density 2.

The interaction for entries x densities was significant ($P < 0.01$) only for stalk lodging and barren plants. Entries x densities was significant for yield in three of the eight environments; however, entries x densities x environments, which was used in the F-test for entries x densities in the combined analysis (Table 3), was significant ($P > 0.05$). Although eight testcrosses had positive linear regression coefficients and 68 testcrosses had negative linear values for yield trends from Density 1 to Density 3 over all environments, the entries x densities-linear was significant at only P = 0.10. The differences among groups and between groups and control for linear effects (Table 2) were not significant.

Relative yields among the groups averaged over all environments were similar in each of the densities (Table 4). Group 3 had the highest yield in all densities, and Group 2 had the lowest, but differences among the groups were not significant in any density. Among groups x environments was significant in Density 1 and highly significant in densities 2 and 3. The average yield of the groups was significantly greater than the control in Density 3. The ranges in testcross mean yields for each group show no consistent characteristics among the three densities. Group 3 had the highest incidence of root and stalk lodging in all densities and the lowest incidence of barren plants in densities 2 and 3.

Agronomic data for the five groups of testcrosses and the control, evaluated in the experiments with rows spaced 51 cm (Experiment II), are presented in Table 5, and results of the combined analysis for yield in Table 6. Yield differences among all entries were highly significant, and the interaction with years was not significant. A comparison of testcrosses of selections vs. control was not obtained in the combined analysis, but the difference was only 0.4 q/ha. Differences among groups 1 to 4 were highly significant; the interaction with years was significant at P = 0.10. On the basis of Duncan's New Multiple Range Test, Group 3 yielded more than groups 1 and 2 (P = 0.05), and groups 1 and 4 yielded more than Group 2. Group 5, which comprised testcrosses of 10 lines selected on the basis of testcross performance, did not yield differently from the control. Obviously, this group did not yield differently from groups 1, 3, and 4, but it did yield higher than Group 2. Group 3 had more total lodging and fewer barren plants than any other group.

Table 4. Agronomic data for testcrosses of four groups of inbred selections and the control at three plant densities averaged over eight environments, Experiment I.

Material	Yield: Mean q/ha	Yield: Range q/ha	Moisture %	Lodged: Root %	Lodged: Stalk %	Barren plants %
Density-39000 plants/ha						
Group 1	65.3	60.0-73.2	22.2	7.4	6.5	
Group 2	64.7	57.0-71.7	22.2	5.6	6.2	
Group 3	66.2	60.2-75.3	22.0	8.8	7.9	
Group 4	65.4	56.8-74.6	22.7	6.4	6.4	
Control	64.5		23.5	8.6	9.0	
Density-54000 plants/ha						
Group 1	64.2	56.6-75.3	22.9	12.4	11.4	9.3
Group 2	63.7	56.6-68.9	22.6	10.8	11.4	9.3
Group 3	67.0	55.9-73.6	22.4	14.5	13.1	6.1
Group 4	65.7	54.8-73.0	23.1	10.8	11.8	8.7
Control	64.9		23.3	11.2	13.2	8.8
Density-69000 plants/ha						
Group 1	59.7	50.4-67.7	23.0	11.8	15.6	17.9
Group 2	59.2	53.1-69.2	23.2	10.1	14.7	18.7
Group 3	62.2	49.4-70.6	22.8	15.0	20.0	12.3
Group 4	60.7	58.0-66.0	23.4	9.5	16.0	17.2
Control	58.4		23.9	12.0	18.7	16.9

Table 5. Agronomic data for testcrosses of five groups of inbred selections and the control averaged for two trials in Experiment II.

Material	Yield: Mean q/ha	Yield: Range q/ha	Moisture %	Lodged‡: Root %	Lodged‡: Stalk %	Barren plants‡ %
Group 1	89.9	83.2-99.6	23.2	5.9	4.2	4.5
Group 2	86.0	72.8-99.3	23.6	3.1	3.8	5.9
Group 3	92.4	80.1-104.0	23.7	5.6	7.4	3.5
Group 4	91.2	80.0-100.1	24.0	2.6	6.0	4.5
Group 5	90.9	81.2-99.1	23.3	5.0	5.4	3.9
Control	89.7		23.9	2.9	8.2	3.8
S.E.	2.30					

‡Data for 1975 only.

Table 6. Analysis of variance for grain yields of testcrosses of five groups of selections and the control for data combined for two trials, 1974 and 1975, Experiment II.

Source	D.F.	Mean squares
Entries	89	229.89**
Among all groups	5	530.27
Among Groups 1-4	3	864.95**
Remainder	2	28.24
Within Group 1	18	139.14**
Within Group 2	18	283.40**
Within Group 3	18	238.37**
Within Group 4	18	213.82**
Within Group 5	9	207.56**
Within Control	3	65.07
Entries x years	89	65.52
Among all groups x years	5	170.38*
Among Groups 1-4 x years	3	159.69†
Remainder x years	2	186.42†
Within all groups x years	74	67.29
Pooled error	302	64.27

†, *, **Significant at the 10%, 5%, and 1% levels.

Differences among the groups for barren plants are approximately equivalent to differences among the groups for yield.

Data for individual testcrosses are not shown. When the L.S.D. (0.05) and yields of the control were used as bases for comparisons in Experiment I, Group 2 had fewer high-yielding testcrosses than any other group in densities 2 and 3. Group 3 tended to have a higher number of high-yielding testcrosses, although groups 1, 3, and 4 were similar in Density 3. The greatest superiority of Group 3 and inferiority of Group 2 were in Experiment II, which was hand harvested, and therefore had no harvest losses.

Test of inbred lines

Climatic conditions were favorable for plant growth until near anthesis in 1975 when some drought stress occurred. Several inbred lines showed some evidence of stress either by top-leaf firing or extensive leaf rolling. Again in 1976, conditions

Table 7. Mean values for 13 inbred traits at two plant densities and average of the densities for four groups of inbred lines.

	Days to‡ Pollen	Silk	Silk delay days	Height Plant cm	Ear cm	Leaf area cm^2	Row No.	Ear Length cm	Diameter cm	Kernel depth cm	Ears/ plant	Wt/300 K g	Yield q/ha
							Density 1						
Group 1	24.5	26.9	2.4	131.6	54.0	651.6	13.9	17.8	3.8	0.6	1.2	71.7	29.6
Group 2	25.6	28.8	3.2	130.8	55.3	656.1	15.4	15.8	3.9	0.6	1.0	69.4	27.8
Group 3	27.2	29.0	1.8	133.0	63.2	658.6	13.7	20.7	3.6	0.5	1.6	69.2	30.7
Group 4	24.9	27.6	2.7	124.0	53.1	653.6	14.4	17.3	3.8	0.6	1.2	72.5	29.8
Mean	25.6	28.1	2.6	129.9	56.4	655.0	14.3	17.9	3.8	0.6	1.3	70.6	29.5
							Density 2						
Group 1	24.8	28.2	3.4	134.9	58.6	636.9	13.6	13.0	3.7	0.6	1.0	68.9	41.7
Group 2	26.5	30.4	3.9	135.3	60.0	619.5	14.7	11.7	3.8	0.6	0.9	66.8	39.2
Group 3	28.1	30.7	2.6	138.5	69.2	612.0	13.4	13.5	3.6	0.6	1.1	66.9	38.8
Group 4	25.6	28.8	3.2	128.1	57.3	623.4	14.0	13.0	3.8	0.7	1.0	69.2	41.4
Mean	26.3	29.3	3.0	134.2	61.2	622.9	13.9	12.8	3.7	0.6	1.0	67.9	40.2
							Average						
Group 1	24.6	27.6	3.0	133.2	56.3	644.2	13.7	15.4	3.7	0.6	1.1	70.3	35.7
Group 2	26.1	29.6	3.5	133.0	57.7	637.8	15.1	13.8	3.8	0.6	0.9	68.1	33.5
Group 3	27.7	29.9	2.2	135.8	66.2	635.3	13.5	17.1	3.6	0.6	1.3	67.6	34.7
Group 4	25.3	28.2	2.9	126.1	55.2	638.5	14.2	15.1	3.8	0.6	1.1	70.8	35.6
Mean	25.9	28.8	2.9	132.0	58.8	639.0	14.1	15.3	3.7	0.6	1.1	69.2	34.9

‡Days after June 30.

were favorable for plant growth until late June when severe damage was caused by a hailstorm, which was followed by much below average rainfall for the rest of the season. In spite of the adverse conditions, the average yields over all lines were higher at the higher density in both years, 40.2 q/ha (Density 2) vs. 29.5 q/ha (Density 1) for the average of the 2 years.

Mean values are presented in Table 7 for 13 plant, ear, and grain characters for groups 1 to 4 at two plant densities and the average, combined for the 2 years. The combined analyses of variance with orthogonal comparisons for among and within the groups are given in Table 9. Orthogonal comparisons within entries x densities are not shown because few were significant.

Differences among entries were highly significant for all traits. Also, entries x years was highly significant for all traits, but the estimated components for the interactions were of considerably lesser magnitude than for the main effects of entries. Entries x densities was highly significant for plant height, ear height, ear length, and ears per plant, and it was significant for days to silk, leaf area, and yield. In most instances, entries x densities was of less importance than entries x years. The second-order interaction was highly significant for six traits, but usually was of less importance than either of the first-order interactions.

Highly significant differences were detected among group means for all traits except leaf area and yield. Both leaf area and yield had highly significant mean squares for among groups x years, and leaf area was highly significant for among groups x densities. Mean yields of the four groups, averaged for densities and years, varied only from 33.5 to 35.7 q/ha, with Group 2 having the lowest average yield and Group 1, the highest (Table 8). Group 2 had the greatest within-group variation for yield, with a range of 6.5 to 49.7 q/ha, and Group 1 had the least within-group variation, with a range of 23.2 to 45.9 q/ha. The highest yield was for a selection in Group 4, 56.3 q/ha. Barrenness was the main cause for some selections in Group 2 to have low yields. Although leaf areas for the groups, averaged over densities and years, were similar, the

Table 8. Mean yields and ranges in yields at two plant densities and average of the densities for four groups of inbred lines.

Group	Density 1 Mean	Range	Density 2 Mean	Range	Average Mean	Range
1	29.6	18.2-38.4	41.7	27.0-59.4	35.7	23.2-45.9
2	27.8	6.3-39.5	39.2	6.6-63.6	33.5	6.5-49.7
3	30.7	17.3-40.6	38.8	21.8-66.0	34.7	19.6-51.8
4	29.8	19.4-43.8	41.4	22.3-68.8	35.6	21.9-56.3
$\bar{x}$	29.5		40.2		34.9	

Yields (q/ha)

Table 9. Combined analyses of variance with orthogonal comparisons for 12 plant, ear, and grain characters for 81 inbred selections evaluated in low and high plant densities at the Agronomy Farm in 1975 and 1976.

Source	D.F.‡	Days to tassel	Days to silk	Plant height	Ear height	Leaf area	Ear row no.
Years (Y)	1	11215.92	12607.92	25909.81	38239.23	3124907.10	155.28
Densities (D)	1	104.04	463.35	4717.69	5489.81	242413.14	43.19
D x Y	1	0.36	0.30	536.89	58.08	225.03	0.07
Entries	80	81.88**	85.30**	2181.14**	1282.37**	59565.09**	24.06**
Groups 1, 2, 3, 4 vs 5	1	408.76**	193.69**	63.54	168.32	6329.76	159.49**
Among 1, 2, 3, 4	3	391.68**	276.69**	3923.47**	5779.26**	3279.23	103.25**
Within 1	18	95.85**	85.53**	2566.47**	774.54**	90922.99**	24.79**
Within 2	18	36.31**	52.17**	1305.72**	505.74**	58704.55**	18.08**
Within 3	18	37.59**	52.70**	2499.21**	1834.01**	55069.64**	13.93**
Within 4	18	81.66**	106.20**	2097.41**	997.39**	48592.46**	22.48**
Within 5	4	110.29**	115.31**	2554.69**	2768.35**	47456.49**	7.14**
Entries x Y	80	7.63**	9.30**	118.82**	115.69**	9181.92**	1.58**
Groups 1, 2, 3, 4 vs 5 x Y	1	15.79**	7.24	135.76*	603.79**	60504.36**	0.36
Among 1, 2, 3, 4 x Y	3	19.10**	7.86*	162.53**	170.79**	16725.52**	2.73**
Within 1 x Y	18	6.59**	5.37**	55.48**	63.04**	9827.68**	1.32**
Within 2 x Y	18	6.29**	12.43**	105.42**	115.72**	5754.01**	1.36**
Within 3 x Y	18	7.08**	8.73**	107.35**	93.10**	10637.07**	1.45**
Within 4 x Y	18	9.44**	9.13**	196.65**	135.85**	4269.20	2.09**
Within 5 x Y	4	2.09	17.87**	129.59**	182.16**	18772.23**	1.49*
Entries x D	80	1.73	2.76*	53.86**	33.64**	3834.45*	0.62
Entries x Y x D	80	2.49**	2.46	25.12	18.19	3112.47	0.64
Pooled error		1.73	2.00	26.64	13.90	2797.18	0.55
		(586)	(568)	(544)	(544)	(592)	(592)

‡d.f. for pooled error is shown in brackets for each trait. Number is variable because in some environments the lattice was not used.

Table 9. (continued)

Source	D.F.	Ear length	Ear diameter	Kernel depth	Ears/plant	Wt/300 kernels	Yield
Years (Y)	1	20.73	0.301	0.117	0.301	16787.61	898.45
Densities (D)	1	6028.59	1.021	0.306	17.682	1963.52	30016.67
D x Y	1	48.13	4.604	1.070	0.441	19.00	211.40
Entries	80	95.52**	0.773**	0.098**	0.594**	1282.27**	871.28**
Groups 1, 2, 3, 4 vs 5	1	56.86*	1.164**	0.133**	0.318	1549.92**	1.50
Among 1, 2, 3, 4	3	416.28**	2.587**	0.250**	6.179**	571.53**	237.20
Within 1	18	67.62**	0.604**	0.056**	0.228*	1247.52**	514.11**
Within 2	18	95.73**	0.745**	0.098**	0.415*	1506.80**	1319.93**
Within 3	18	66.25**	0.638**	0.074**	0.464**	734.80**	703.91**
Within 4	18	45.65**	0.716**	0.120**	0.170**	1777.81**	888.78**
Within 5	4	345.31**	1.070**	0.173**	1.427**	1128.13**	1827.10**
Entries x Y	80	10.43**	0.061**	0.013**	0.121**	138.17**	188.35**
Groups 1, 2, 3, 4 vs 5 x Y	1	48.06**	0.000	0.000	0.609**	105.45	189.49**
Among 1, 2, 3, 4 x Y	3	18.66**	0.083*	0.017	0.260**	170.73**	289.68**
Within 1 x Y	18	8.38**	0.050*	0.015**	0.076**	132.86**	146.02**
Within 2 x Y	18	9.74**	0.075**	0.016**	0.173**	115.24**	291.24**
Within 3 x Y	18	14.77**	0.061**	0.010	0.146**	159.09**	212.36**
Within 4 x Y	18	6.53	0.070**	0.015**	0.056*	116.76**	120.68**
Within 5 x Y	4	5.17	0.017	0.004	0.050	251.21**	36.09
Entries x D	80	24.52**	0.072	0.012	0.128**	52.83	144.31*
Entries x Y x D	80	9.55**	0.052**	0.011**	0.051**	32.18	87.97**
Pooled error		4.63	0.028	0.007	0.030	43.60	22.17
		(544)	(568)	(616)	(544)	(544)	(568)

range for leaf area among selections was large, and was greatest in Group 1.

For the other 10 characters, the variation among groups was more consistent between the two densities. Considering group means averaged for the densities, the following items are noteworthy:

(1) Group 3 had the latest dates for days to pollen shed and silk emergence, and Group 1 had the earliest. Group 3 had the least delay for silk emergence, and Group 2 had the greatest.

(2) Group 3 had the highest values for plant and ear heights, and Group 4 had the lowest.

(3) Group 2 had the greatest ear row number and diameter, but the shortest ear length. Group 3 had the greatest ear length. Probably, Group 2 had the shortest ear length because it had fewer second ears and more barren plants, and ear length was based on all plants including those that had no harvestable ears.

(4) Within the groups, there was highly significant variation for all traits, but the extent of the variation was not consistently greatest in any one group.

Correlation studies

(a) *Correlations among inbred traits:* Simple correlation coefficients among 13 plant, ear, and grain traits of the inbred lines in the low density (Density 1) are presented in Table 10. Significant r-values were obtained for days to pollen shed and ear diameter with six other traits; days to silk, silk delay, ear height, and weight/300 kernels with four traits; for plant height and leaf area with three traits; for ear row number with five traits; for ear length and ears per plant with eight traits; and for kernel depth with seven traits. Yield was correlated with six traits, and the highest r-values were with ear length (r= 0.56**) and ears per plant (r = 0.46**). Among the ear and grain traits, ear length and ears per plant had the highest correlation, with r = 0.73**. An increase in silk delay caused a decrease in ears per plant (r = −0.30**), which would be expected if the delay was great enough so that pollination would not take place.

Significant r-values at the high plant density (Density 2) were obtained for days to pollen shed, days to silk, silk delay, ear diameter, and weight/300 kernels with five traits; for plant height, ear row number, and ear length with three traits; for ear height and kernel depth with four traits; for leaf area with one trait; and ears per plant with six traits (Table 11). Yield was correlated with seven traits, and the highest significant correlations were with ear length (r = 0.69**) and kernel depth (r = 0.52**). Among the ear and grain traits, again ear length and ears per plant had the highest correlation with r = 0.70**. Also in Density 2, an increase in silk delay caused a decrease in ears per plant (r = -0.47**).

When the two densities were compared, the number of significant correlations was greater for ear and grain traits than for plant traits in Density 1, whereas in Density 2, the number of significant correlations was distributed more equally among all traits. There were 38 instances where the r-value

Table 10. Simple correlation coefficients among 13 plant, ear, and grain traits for 76 inbred lines at Density 1 (29,500 plants/ha).

Traits	Days to pollen	Days to silk	Silk delay	Plant height	Ear height	Leaf area	Ear row no.	Ear length	Ear diameter	Kernel depth	Ears/ plant	Wt/300 kernels
Days to silk	0.85**											
Silk delay	-0.18	0.36**										
Plant height	0.23*	0.22*	0.02									
Ear height	0.24*	0.21	0.03	0.64**								
Leaf area	0.20	0.19	0.02	0.17	-0.04							
Ear row no.	-0.03	-0.01	0.03	0.02	-0.11	-0.13						
Ear length	0.30**	0.14	-0.27*	0.15	0.26*	0.31**	-0.42**					
Ear diameter	-0.18	-0.11	0.12	0.08	-0.07	0.14	0.57**	-0.32**				
Kernel depth	-0.24*	-0.25*	-0.03	0.10	-0.06	0.10	0.28**	-0.21	0.66**			
Ears/plant	0.34**	0.17	-0.30**	0.09	0.33**	-0.02	-0.30**	0.73**	-0.41**	-0.27*		
Wt/300 kernels	-0.05	0.00	0.11	0.12	0.05	0.33**	-0.28**	-0.10	0.35**	0.36**	-0.20	
Yield	-0.02	-0.18	-0.32**	0.21	0.17	0.24*	0.03	0.56**	0.29**	0.38**	0.46**	0.16

*,**Significant at the 5 and 1% levels of probability, respectively.

Table 11. Simple correlation coefficients among 13 plant, ear, and grain traits for 76 inbred lines at Density 2 (59,000 plants/ha).

Traits	Days to pollen	Days to silk	Silk delay	Plant height	Ear height	Leaf area	Ear row no.	Ear length	Ear diameter	Kernel depth	Ears/plant	Wt/300 kernels
Days to silk	0.81**											
Silk delay	-0.24*	0.36**										
Plant height	0.38**	0.35**	-0.01									
Ear height	0.39**	0.29**	-0.13	0.66**								
Leaf area	0.08	0.12	0.05	0.13	-0.11							
Ear row no.	-0.02	-0.02	0.00	-0.03	-0.16	-0.10						
Ear length	0.10	-0.14	-0.40**	0.12	0.18	0.20	-0.15					
Ear diameter	-0.06	-0.03	0.05	0.06	-0.06	0.05	0.52**	-0.02				
Kernel depth	-0.12	-0.15	-0.06	0.06	-0.08	0.11	0.22*	0.02	0.64**			
Ears/plant	0.31**	0.02	-0.47**	0.08	0.34**	-0.07	-0.20	0.70**	-0.29**	-0.18		
Wt/300 kernels	0.02	0.07	0.08	0.16	0.03	0.23*	-0.41**	0.01	0.35**	0.37**	0.09	
Yield	-0.02	-0.26*	-0.40**	0.16	0.10	0.18	0.16	0.69**	0.47**	0.52**	0.37**	0.24*

*,**Significant at the 5 and 1% levels of probability, respectively.

was significant in one or both densities, and 19 were higher in Density 1, 17 were higher in Density 2, and two were equal. Consequently, we cannot conclude that one density has been better than the other for evaluating the relationship among traits of the inbred lines.

(b) *Simple correlations between inbred traits and hybrid yields:* Simple correlation coefficients are presented in Table 12 between 13 plant, ear, and grain traits of the inbred lines in the low plant density (Density 1) and yields of the hybrids in low, intermediate, and high plant densities (Densities 1, 2, and 3, respectively), and average of the densities. Significant r-values between inbred traits and hybrid yields were obtained for three, five, and four traits in Densities 1, 2, and 3, respectively. The r-values were significant for leaf area, weight/300 kernels, and yield in all densities of the hybrids; for days to pollen and silk in Density 2; and for ear length in Density 3. The highest correlation was 0.39** for leaf area in Density 1. There were no consistent trends across the three densities for magnitudes of the r-values. Also, for the average of hybrid yields over densities, the relationships between inbred traits and hybrid yields were no better than for individual densities.

Table 12. Simple correlation coefficients between 13 traits of the inbred parents at Density 1 and hybrid yields in three plant densities and average of the densities (Experiment I).

Inbred traits	Correlation values			
	Density 1	Density 2	Density 3	Average
Days to pollen	0.11	0.25*	0.17	0.20
Days to silk	0.05	0.22*	0.17	0.17
Silk delay	-0.09	-0.04	0.01	-0.04
Plant height	0.18	0.11	0.15	0.16
Ear height	-0.01	0.06	0.08	0.05
Leaf area	0.39**	0.32**	0.25*	0.34**
Ear row no.	-0.05	-0.13	-0.12	-0.11
Ear length	0.18	0.21	0.23*	0.23*
Ear diameter	0.17	0.10	0.10	0.13
Kernel depth	0.12	0.09	0.05	0.10
Ears/plant	0.15	0.19	0.20	0.20
Wt/300 kernels	0.27*	0.31**	0.36**	0.35**
Yield	0.33**	0.28**	0.33**	0.34**

*,**Significant at the 5 and 1% levels of probability.

Significant r-values between inbred traits in the high density and hybrid yields in Densities 1, 2, and 3 and average of the three densities were obtained for five, five, and six traits in Densities 1, 2, and 3, respectively (Table 13). The r-values were significant for ear length, weight/300 kernels, and yield in all densities; leaf area in Density 1; days to pollen and ears per plant in Density 2; silk delay and plant height in Density 3; and ear diameter in Densities 1 and 3. For the three traits significant in all densities, the r-values had small increases from Density 1 to Density 3. The correlations for the average of the three densities were essentially an average of the r-values for the densities of the hybrids.

Table 13. Simple correlation coefficients between 13 traits of the inbred parents at Density 2 and hybrid yields in three plant densities and average of the densities (Experiment I).

Inbred traits	Correlation values Density 1	Density 2	Density 3	Average
Days to pollen	0.11	0.22*	0.20	0.20
Days to silk	0.02	0.14	0.06	0.08
Silk delay	-0.13	-0.12	-0.22*	-0.18
Plant height	0.21	0.17	0.22*	0.22*
Ear height	0.03	0.11	0.13	0.10
Leaf area	0.37**	0.20	0.18	0.26*
Ear row no.	-0.02	-0.07	-0.12	-0.08
Ear length	0.40**	0.41**	0.43**	0.46**
Ear diameter	0.24*	0.17	0.23*	0.23*
Kernel depth	0.19	0.13	0.14	0.17
Ears/plant	0.18	0.26*	0.19	0.23*
Wt/300 kernels	0.30**	0.31**	0.37**	0.36**
Yield	0.42**	0.40**	0.43**	0.46**

*,**Significant at the 5 and 1% levels of probability.

When the simple correlation coefficients obtained between inbred traits and hybrid yields were compared for Densities 1 and 2 of the inbreds, the number of significant r-values was slightly greater for Density 2. Also, the r-values had a slightly greater magnitude in Density 2 of the inbreds, except between leaf area and hybrid yield for which the higher values were in Density 1. Between ear length and hybrid yield, the r-values were highly significant for Density 2 of the inbreds with all densities of the hybrids, but for Density 1 of the inbreds, only the r-value in Density 3 of the hybrids was significant. Generally, the best relationships were obtained for inbred traits in Density 2 and hybrid yields in Density 3.

Simple correlation coefficients for 13 plant, ear, and grain traits of the inbreds with hybrid yields in Experiment II showed that leaf area was the only plant trait that had a significant r-value with hybrid yields in Density 1; none of the plant traits had significant r-values in Density 2 (Table 14). For Density 1, weight/300 kernels and yield were significantly correlated with hybrid yields, whereas for Density 2, significant correlations also were obtained for ear length, ear diameter, and ears per plant. The kernel weight relationship increased only slightly from Density 1 to Density 2, but for the other four traits the relationships increased considerably.

Some differences are evident between these r-values and the r-values presented previously in Experiment I. Experiment I had more significant r-values for inbred plant traits with hybrid yields, but the relationship for inbred leaf area with hybrid yields for comparable plant densities was similar in the two experiments. Ear length and yield of the inbreds with hybrid yields had stronger relationships in Experiment I than in Experiment II. Such comparisons, however, may be confounded by environmental effects because the hybrid yield data were obtained in eight environments for Experiment I and in two environments for Experiment II.

(c) *Multiple correlation between inbred traits and hybrid yields:* Multiple correlation values (R) between 13 inbred traits in Density 1 and hybrid yields in Densities 1, 2, and 3 and average for all densities of Experiment I are presented in Table 15. Similar R-values for Density 2 of the inbreds are presented in Table 16. For both inbred densities, the highest R-values were obtained when hybrid yields were correlated with all 13 inbred traits. Also, for both densities, when yield was correlated with three different sets of ear and grain traits, the R-values were similar among the sets and were not much lower than the R-values with all 13 traits. Thus, ear length, weight/300 kernels, and yield of the inbreds had nearly as high predictive value for hybrid yields as did all ear and grain traits. The plant traits had lower R-values and, therefore, would have lower predictive values for hybrid yields. The R-values were higher for Density 2 than for Density 1 of the inbreds. Also, R-values between inbred ear and

Table 14. Simple correlation coefficients between 13 traits of the inbred parents in two plant densities, and average of the densities, and hybrid yields in Experiment II.

Inbred traits	Correlation values Density 1	Density 2	Average
Days to pollen	0.16	0.16	0.16
Days to silk	0.10	0.08	0.09
Silk delay	-0.09	-0.12	-0.11
Plant height	0.04	0.11	0.07
Ear height	-0.01	0.05	0.02
Leaf area	0.22*	0.21	0.22*
Ear row no.	-0.18	-0.16	-0.18
Ear length	0.10	0.34**	0.22*
Ear diameter	0.11	0.24*	0.17
Kernel depth	0.10	0.19	0.18
Ears/plant	0.16	0.25*	0.21*
Wt/300 kernels	0.46**	0.48**	0.48**
Yield	0.23*	0.39**	0.35**

*,**Significant at the 5 and 1% levels of probability.

Table 15. Multiple correlation coefficients between traits of inbred parents (Density 1) and hybrid yields (Densities 1, 2, 3, and average) in Experiment I as computed for plant, ear and grain traits and combined for all traits.

Traits correlated‡	Multiple correlation coefficients			
	Density 1	Density 2	Density 3	Average
R14 vs 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13	0.54*	0.52	0.54*	0.56*
R14 vs 1, 2, 3, 4, 5, 6	0.43*	0.38	0.30	0.38
R14 vs 7, 8, 9, 10, 11, 12, 13	0.42*	0.42*	0.51**	0.49**
R14 vs 7, 8, 9, 10, 11, 12	0.40	0.42*	0.49**	0.48**
R14 vs 8, 12, 13	0.40**	0.41**	0.47**	0.47**

‡Key to traits: 14 = hybrid yield, 1 = days to pollen, 2 = days to silk, 3 = silk delay, 4 = plant height, 5 = ear height, 6 = leaf area, 7 = ear row number, 8 = ear length, 9 = ear diameter, 10 = kernel depth, 11 = ears per plant, 12 = 300-kernel weight, 13 = inbred yield.

*,**Significant at the 5 and 1% levels of probability.

Table 16. Multiple correlation coefficients between traits of inbred parents (Density 2) and hybrid yields (Densities 1, 2, 3, and average) in Experiment I as computed for plant, ear, and grain traits and combined for all traits.

Traits correlated‡	Multiple correlation coefficients			
	Density 1	Density 2	Density 3	Average
R14 vs 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13	0.61**	0.60**	0.64**	0.65**
R14 vs 1, 2, 3, 4, 5, 6	0.46**	0.35	0.36	0.40
R14 vs 7, 8, 9, 10, 11, 12, 13	0.53**	0.53**	0.60**	0.60**
R14 vs 7, 8, 9, 10, 11, 12	0.53**	0.53**	0.59**	0.60**
R14 vs 8, 12, 13	0.51**	0.51**	0.57**	0.58**

‡Key to traits: 14 = hybrid yield, 1 = days to pollen, 2 = days to silk, 3 = silk delay, 4 = plant height, 5 = ear height, 6 = leaf area, 7 = ear row number, 8 = ear length, 9 = ear diameter, 10 = kernel depth, 11 = ears per plant, 12 = 300-kernel weight, 13 = inbred yield.

*,**Significant at the 5 and 1% levels of probability.

grain traits and hybrid yields increased from Density 1 to Density 3, but between plant traits and hybrid yields there was a decrease from Density 1 to Density 3.

The highest R-values in Densities 1 and 2 of Experiment II of the inbreds were obtained when all inbred traits were correlated with hybrid yields (Table 17). The R-values were almost as high when only inbred ear and grain traits were considered. In all comparisons except plant traits, the highest R-values were observed in Density 2 of the inbreds. The R-values obtained for Experiment II are similar to those given previously for Experiment I for comparable plant densities.

Table 17. Multiple correlation coefficients between traits of inbred parents (Densities 1, 2, and average) and hybrid yields in Experiment II as computed for plant, ear, and grain traits and combined for all traits.

Traits correlated‡	Multiple correlation coefficients Density 1	Density 2	Average
R14 vs 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13	0.59**	0.66**	0.61**
R14 vs 1, 2, 3, 4, 5, 6	0.34	0.32	0.29
R14 vs 7, 8, 9, 10, 11, 12, 13	0.54**	0.60**	0.58**
R14 vs 7, 8, 9, 10, 11, 12	0.53**	0.60**	0.58**
R14 vs 8, 12, 13	0.49**	0.59**	0.55**

‡Key to traits: 14 = hybrid yield, 1 = days to pollen, 2 = days to silk, 3 = silk delay, 4 = plant height, 5 = ear height, 6 = leaf area, 7 = ear row number, 8 = ear length, 9 = ear diameter, 10 = kernel depth, 11 = ears per plant, 12 = 300-kernel weight, 13 = inbred yield.

*,**Significant at the 5 and 1% levels of probability.

DISCUSSION

Results from an evaluation of maize breeding methods probably are most useful when the environments have a range in yield potential, as in Experiment I of this study. We had three low-yield environments, two of which were caused primarily by moisture stress at pollination and later. Although two environments had relatively high yield levels, there was none in which any group of selections had greatest average testcross yield at the high plant density. A few testcrosses did produce more grain in Density 3 than in either Density 1 or Density 2. Probably the most important limiting factors to grain yield were soil moisture and genotype, which included both the tester and lines being tested. There were no obvious signs of nutrient deficiencies.

Undoubtedly, excessive lodging in some high-yield environments, particularly at the high plant density, caused harvest losses that confounded the yield results; therefore, the total yield potential of some testcrosses was not obtained. Probably, the effect would be greatest for Group 3 because it had the most lodging. Also, at the Agronomy Farm in 1975 where lodging was excessive, Group 3 had the least incidence of barren plants, but yielded less relative to other groups than it did in most experiments. The Agronomy Farm in 1975 was the best yield environment for Group 2, relative to the other groups, even though this group had the highest percentage of barren plants. In this environment, Group 2 had the lowest percentage for lodging in all densities. If hand-harvesting of the experiments with the three plant densities had been used, total yields would have been measured. Maize breeders in the U.S. Corn Belt, however, must develop hybrids that will be harvested by machine.

Considering the evaluation of the inbred lines *per se*, we did not have environments that would permit an expression of maximum yield potential of any genotype. Certainly, 1976 was very atypical because of the extensive hail damage followed by severe drought. Even though we had some severe drought stress in midsummer of 1975, it was probably more nearly typical because this is a usual occurrence in central Iowa. In spite of the unfavorable growing seasons, four inbred lines exceeded 60 q/ha in Density 2 as an average for the 2 years, and two of these exceeded 70 q/ha in 1975. By contrast, six lines yielded less than 25 q/ha in Density 2 as an average of the 2 years, and one had only 6.6 q/ha because it had 60% barren stalks. One would not expect such a low-yielding line to have survived through five generations of selection.

We have no way to assess our progress in selecting lines with yields better on the average than would be observed for a random set of lines from BS1. Russell and Teich (1967) found in two groups selected visually from M14 x C103 that 37.5% of the lines yielded significantly more than the best parent. They also found that their Group 4 (equivalent to our Group 1) yielded significantly more than their Group 3 (equivalent to our Group 2), and the difference was greater in the higher density. Our Group 1 yielded more than Group 2, but the difference was not significant and the differences were similar in the two plant densities.

The inbreds developed on the basis of phenotype were selected through four successive inbreeding generations, S_1 to S_4. Selection was rigorous for all plant and ear traits that seemed desirable for inbreds that would be used in hybrids. These traits included vigorous plant appearance (except that excessively tall genotypes were eliminated), concurrent tassel dehiscence and silk emergence, and high seed yield. If there is a positive relationship between vigor characteristics of parent inbred lines and yield in their testcrosses one would have expected some gain in combining ability when compared with a comparable testcross of the source population. Even though 17% of the visually selected lines tested in Experiment I and 19% in Experiment II yielded significantly more than the control (L.S.D., 0.05), the average gains for the groups were disappointingly small and, indeed, may have even averaged negative in the lines selected for single-eared plants in a low plant density (Group 2). Perhaps one cause for greater gains not being realized was that the selected materials were earlier than the control in testcross evaluations (Table 2), and there is usually a positive correlation between days to maturity and yield.

The applied maize breeder is more concerned with performance of the best lines than with group comparisons. The 10 highest-yielding testcrosses in Experiment I, based on averages over all densities, were distributed among the groups as follows: Group 1, 4; Group 2, 1; Group 3, 4; and Group 4, 1. Similarly, in Experiment II the distribution of the 10 highest yielding testcrosses was: Group 1, 2; Group 2, 1; Group 3, 3; Group 4, 3; and Group 5, 1. In both sets of experiments, Group 2 contributed the lowest number of high yielding testcrosses. Similar data for the 10 lowest-yielding testcrosses did not favor any group in Experiment I, but Group 2 contributed the most low-yielding testcrosses in Experiment II. The data do not support selection for single-eared lines in a low plant density.

Vigorous selection pressures were used, but the results relative to yield performance in testcrosses were not greatly different from those observed in previous studies. Sprague and Miller (1952) found no positive gain in combining ability for successive generations where visual selection was practiced among and within progenies. Brown (1967) reported evidence that visual ratings of a random set of inbred lines were not satisfactory criteria for hybrid yield performance. The results for groups 1 and 2 are very similar to results that Russell and Teich (1967) observed for two groups of lines developed from M14 x C103 by almost identical procedures. As an average for the two groups, they observed a gain relative to the control of only 1.6 q/ha, which was not significant, and the group selected in the high plant density yielded 2.0 q/ha more than the group selected in the low plant density, which was significant. Russell and Teich (1967) also found that barren stalks seemed to be the main cause for the yield difference of the two groups. They concluded that it would be desirable to develop inbred lines at the high plant density, but, in part, their conclusion was based on the seed yields of the inbred lines *per se* in which the high-density group yielded significantly more than the low-density group.

When this research was started, there was limited evidence for the potential of the two-eared type in the U.S. Corn Belt (Collins et al., 1965; Russell, 1968). Recent studies have shown that the two-eared or prolific type of maize may be an important means by which Corn Belt hybrid yields can be increased in the future (Hallauer, 1973; Prior and Russell, 1975). Although the advantage relative to the other groups was small and inconsistent, greater yields were realized for the two-eared selections (Group 3). The data suggested further that the advantage of the two-eared lines resulted because they were better able to produce ears in stress environments. Of even greater significance, however, is that selection for single-eared genotypes at a low plant density (Group 2) gave lines with below-average hybrid yields and, in one set of experiments, yielded less than the testcross of the source population. This performance seemed strongly related to the greater incidence of barren plants for Group 2. Fasoulas (1976) emphasized that selection should be done in a completely noncompetitive environment that allows "maximal genotypic expression and differentiation." This would be true if selection were for the prolific type, but not if selection were for the single-eared type.

Root and stalk lodging seems an important problem for the two-eared type of maize. The development of stalk-rot-resistant lines was more difficult in Group 3 than in the other groups, and probably, some strongly two-eared selections had to be discarded because of susceptibility to stalk rot. Consequently, before maize breeders can place much effort in the development of two-eared or prolific inbred lines, source populations with better lodging resistance are needed. Selection at a high plant density will be nearly as effective for the development of lines with high hybrid yields, and the lines will have better stalk strength (Table 4). Perhaps even a higher plant density than we used would be more effective in selection for resistance to barrenness.

When this study was begun, there also was some interest in the U.S. Corn Belt in using more closely spaced rows (51 cm) to achieve greater hybrid yields. The closer-spaced rows would give a more uniform plant distribution in the field, which would result in more efficient interception of sunlight. Because the closer-spaced rows would be a different micro-environment from that of the wider-spaced rows commonly used, there was the possibility that the relative performance among hybrids would not be the same in the two environments. Russell (1972) compared 20 single crosses at three plant densities and in rows spaced 51 cm and 102 cm in two relatively high-yield environments. The average yields over all hybrids, densities, and environments were 8% higher for the narrow-row spacing. The genotype x row spacing was not significant, however, indicating that the relative yields of the hybrids were similar in the two row spacings. The parental lines of his hybrids were developed and evaluated in wide-row spacing regimes and at relatively low plant densities. To realize the full advantage for close-row spacing, it may be necessary to have materials that have been developed and evaluated in this kind of environment.

Evaluations in Experiment II, rows spaced 51 cm, did not show any advantage for the testcrosses of the 19 selections in Group 4 or of the 10 selections in Group 5. Indeed, the relative yields among the groups were similar between Experiment I and Experiment II, which had row spacings of 76 and 96.5 cm. These data show no justification for breeders to use more closely spaced rows (51 cm) in breeding nurseries and yield-test experiments. This is a desirable situation because close-spaced rows create some problems in the mechanics of a breeding and testing program. Also, it seemed more difficult to do visual selection in nursery rows spaced 51 cm than where wider-spaced rows were used. The genotypes used in this study, however, do not have strong erect-leaf orientation. With the advent of materials that have more erect-leaf orientation, results may change from those we observed.

Actually, 64 S_0 plants were represented in the 76 visually selected lines because 11 S_0 plants had two progenies each, and one S_0 plant had three progenies. Within each group, we purposely avoided having more than one progeny of an S_0 plant in the final evaluations. For the average yield over all densities and environments, in no instance was the difference between two testcrosses of a pair of related lines, or among the testcrosses in the set of three, great enough to be significant, even though members of a family were selected in different regimes. This supports the statement by Jenkins (1935) that inbred lines "acquired their individuality as parents of topcrosses very early in the inbreeding process and remained relatively stable thereafter." El-Lakany and Russell (1971b) showed that the yield potential for hybrids of lines selected from an F_2 population is determined mainly by the yield level of the F_2 plant from which a line is derived.

Jenkins (1935) proposed early testing to identify superior genotypes in the early segregating generations of inbred development. Sprague (1946) and Lonnquist (1950) showed that early testing was effective in identifying the superior genotypes, and Lonnquist (1950) showed that further selection for yield improvement, based on testcross performance, was possible for three generations after the first. Russell and Teich (1967) found that a testcross procedure in three successive generations of inbred line development produced 12 of 29 lines that yielded significantly more than the testcross of the source from which the lines were developed. In this study, the 10 lines developed on the basis of testcross performance in three successive generations did not show the advantage of early testing found in previous experiments. Furthermore, only one line yielded significantly more than the control, and one was significantly lower. This was a surprising result because, in the third generation when those lines were selected, the average yield of the testcrosses was 7.9 q/ha greater than BS1 x Ia5724, which was highly significant. The only explanation for failure to realize some gain for this group of lines in the final evaluation would seem to be a difference in the environments when the selections were made and the environments for the final evaluations. Russell and Teich (1967) found that, on an average, lines selected visually at a high plant density had an average testcross yield performance that was just as high as two groups of lines developed on the basis of testcross performance. Russell and Teich (1967) concluded that phenotypic selection of inbred lines in a stress environment (high plant density) was just as effective as selection based on testcross performance and, furthermore, that the selection could be at much less cost and in a shorter time. Our results support that conclusion, but we would have to add that selection for the two-eared type in a low plant density may be more effective than selection in a high plant density. Adequate root and stalk strength of the two-eared type may be difficult to obtain, however.

The maize breeder must select for high seed yield in inbred lines, particularly if a line is to be considered for use as a female parent in single-cross seed production. Normally, a detailed evaluation of the lines *per se* is not conducted to obtain the yield and other agronomic data. Instead, the evaluations are visual among progenies and for individual plants within progenies. Consequently, the breeder needs to know the relationships between seed yield and the other plant and ear traits that are amenable to selection.

There were no strong relationships between the inbred plant traits and seed yield. These relationships may have been confounded by selection, however, because the late, tall, high-eared and early, short, less vigorous lines were discarded, which may have also eliminated some of the highest and lowest leaf-area lines. Both Jenkins (1929) and Jugenheimer (1958) found plant height to have a positive, significant correlation with yield. There was a negative, significant r-value for seed yield and silk delay, which was expected because greater delays in silk emergence tend to give more barrenness. There was a negative, significant correlation between silk delay and ears per plant. Rigorous selection for simultaneous silk emergence and pollen during the inbreeding and selection generations will eliminate lines that exhibit silk delay. Usually, one expects a positive relationship between yield and maturity in maize, which was not realized in this study. Perhaps this relationship was not realized because the earliest and latest lines were not selected. Furthermore, in both evaluation seasons, the later flowering lines may have been affected more by the drought stress than were the mid-season and earlier lines. The results indicate that visual selection for desirable plant traits will cause no problems relative to the selection of high-yielding lines.

All ear and grain traits, except ear row number, had positive relationships with inbred seed yields. Jenkins (1929) also found that ear row number and yield were not correlated. Ear length seemed to be the most important yield component, and it was highly correlated with ears per plant. Ear length is a relatively easy trait to select; consequently, the breeder should give close attention to this trait in the development of inbred lines.

From the r-values obtained in the low and high densities, can the breeder decide which density should be used in the breeding nursery? The negative relationship between silk delay and yield was higher in the high density, and this indicates an advantage for the high density because r-values of silk delay with ear length and ears per plant also were negative. The relationships between yield and the other plant traits differed little between the two densities. The relationship between inbred yields and ear and grain traits, except ears per plant, also indicated some advantage for the high density. Consequently, it seems that the high density would be better for selecting high-yielding lines. If, however, two-eared lines are a criterion of selection, then a lower density would be necessary because the two-eared trait may not be expressed in the high density.

If visual selection in inbred development is to be effective in retaining lines that contribute better-than-average yields to hybrids, there must be strong relationship between inbred traits and hybrid yields. Generally, we found that the correlations between inbred plant traits and hybrid yields in Experiment I were low and inconsistent among the density combinations. Inbred leaf areas and hybrid yield were significantly correlated in Experiment I and, in Experiment II, leaf area was the only plant trait to have a significant r-value with hybrid yields. The r-values, however, were too small to be of much predictive value for hybrid yields. Jenkins (1929), Hayes and Johnson (1939), and Russell and Teich (1967) found highly significant r-values between inbred plant heights and hybrid yields. We did not obtain a significant r-value for this relationship and neither did Gama and Hallauer (1977) in their study of 160 random inbred lines and 320 random single-cross progenies.

The highest correlations obtained in our experiment were for ear length, weight/300 kernels, and inbred yields with hybrid yields. In Experiment I, inbred yield in Density 1 and inbred yield and ear length in Density 2 were the best predictors for hybrid yield, but in Experiment II weight/300 kernels was best for both inbred densities. Our r-values for inbred yields with hybrid yields were similar to those in some earlier studies and higher than in several others. In three groups of inbred lines and their single-cross progenies, Jenkins (1929) obtained r-values of 0.67, 0.64, and 0.25. Hayes and Johnson (1939) found a highly significant r-value, but only 0.25. Russell and Teich (1967) found a highly significant correlation ($r = 0.35$), but Gama and Hallauer (1977) obtained values of only 0.09 and 0.11.

Multiple correlation values (R) for all inbred traits with hybrid yields were 0.64** in Experiment I and 0.66** in Experiment II. Hayes and Johnson (1939) obtained a similar value of 0.67 for 12 inbred traits with hybrid yields, but Gama and Hallauer (1977) obtained values of only 0.23 and 0.21 for six inbred traits with hybrid yields. Gama and Hallauer (1977) concluded that "Phenotypic apearance of an inbred line does not seem to be an indicator of its worth in single-cross hybrids." Our data indicated that up to 44% of the variability for yield in the testcrosses was dependent upon 13 inbred traits, but the ear and grain traits were much more important than were the plant traits. Consequently, selecting for inbred yield and yield components would have a favorable effect on obtaining lines that have better-than-average combining ability for yield.

Further support for a relatively strong relationship of inbred yields and yield components with hybrid yields is evident in tables 18 and 19. Grain yields and percentage barren stalks of the five highest- and five lowest-yielding testcrosses are shown in Table 18. These lines were selected on the basis of their mean testcross yields in Density 3, which had the highest r-values in correlation studies. The high group had only a small average yield decrease across densities, whereas the low group had a decrease of 8.9 q/ha. Yield difference

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Table 18. Grain yields and percentage barren stalks for the five highest and the five lowest yielding testcrosses at Density 3 in eight environments.

Selection number	Yield at plant density 39000	54000	69000	Mean	b_1 §	Percentage‡ barren stalks
	---	q/ha	---	---		
4	68.6	64.2	67.7	66.9	-0.48	18.6
34	71.7	67.4	69.2	69.4	-1.29	10.4
53	75.3	69.4	67.6	70.8	-3.82	6.8
54	65.6	69.1	68.0	67.6	1.23	11.4
55	67.5	73.6	70.6	70.6	1.56	9.8
Mean	69.7	68.7	68.6	69.1	-0.54	11.4
18	61.0	56.7	50.4	56.0	-5.27	20.3
27	57.0	56.6	49.7	54.4	-3.66	30.6
39	60.2	55.9	49.4	55.2	-5.39	15.6
63	62.1	54.8	52.4	56.0	-4.88	34.6
65	56.8	55.0	50.8	54.2	-3.01	28.0
Mean	59.4	55.8	50.5	55.2	-4.44	25.8

‡At 69,000 plants/ha.

§Linear regression coefficient.

between the two groups was 10.3 q/ha in Density 1, but this increased to 18.1 q/ha in Density 3. The low group had more than twice as many barren stalks as did the high group (11.4 vs. 25.8%, Table 18).

As an adjunct to the testcross data, agronomic data for the parent inbreds of the testcrosses are shown in Table 19. These data are from the high-density evaluations. The high group yielded 48.4 q/ha and the low group yielded 27.0 q/ha; all lines in the high group yielded more than all lines in the low group. Differences for ear length, ears per plant, and weight/300 kernels contributed to the yield differences. The plant traits also showed important differences, although r-values between inbred plant traits and hybrid yields for all selections did not indicate close relationships. The plant data suggest that selection for later, taller lines with greater leaf area would have some positive effect in obtaining higher testcross yields, but taller lines may contribute less lodging resistance.

A primary objective of our study was to determine the effects of plant densities on the relationships between inbred traits and hybrid yields. Most early studies were conducted with plant densities that were considerably lower than our high densities. We hypothesized that the higher densities, which subject the individual plant to a greater stress environment, may cause stronger relationships between inbred traits and hybrid yields. Studies by Russell and Teich (1967) and El-Lakany and Russell (1971a) suggested this possibility.

Our results showed little effect of plant densities on the relationships between plant traits of the inbreds and yield of their hybrid progenies; the r-values decreased from Density 1 to Density 3 in Experiment I. For inbred ear and grain traits, however, plant densities had some effects on r-values, and the highest r-values were obtained for inbred ear and grain traits in Density 2 with hybrid yields in Density 3. Also, the multiple correlations showed the highest R values for Density 2 of the inbreds with Density 3 of the hybrids. The highest r-value obtained for any comparison showed that the 13 inbred traits accounted for 44% of the variability for yield among the hybrid progenies. Consequently, visual selection in the inbred lines will have positive effects in selecting parent lines that have better-than-random hybrid yield performance, but, with 56% of the variability for yield among the testcrosses unaccounted for, the breeder still must have adequate testcross evaluation for the lines that evolve from the development program.

The lines evaluated would not be a random sample for inbred traits because selections that were too tall, too late, too early, or too low yielding were discarded. One would expect that the discarded selections may have been the extremes in distribution more often than in the modal class. Because the extremes in a distribution may contribute dispropor-

Table 19. Agronomic data in Density 2 for the inbreds per se that were the five highest and five lowest in testcross yield performance (see Table 18).

Selection number	Days to‡ Pollen	Days to‡ Silk	Silk delay days	Height Plant cm	Height Ear cm	Leaf area cm^2	Ear Row no.	Ear length cm	Ear Diameter cm	Kernel depth cm	Ears/ plant	Wt/300 k	Yield q/ha
4	25.0	27.2	2.2	136.0	55.3	687.2	12.6	12.8	3.8	0.8	1.1	73.5	45.8
34	25.4	28.1	2.7	129.6	61.2	652.4	13.4	17.2	4.0	0.7	1.0	71.2	60.2
53	29.0	30.8	1.8	134.3	69.5	636.2	13.0	13.2	3.6	0.6	1.1	56.0	34.0
54	31.0	33.4	2.4	164.6	90.6	532.0	12.1	12.6	3.5	0.6	1.2	76.5	36.2
55	28.0	29.7	1.7	143.2	66.8	583.2	14.4	15.4	4.2	0.7	1.0	79.4	66.0
Mean	27.7	29.8	2.1	141.5	68.7	618.2	13.1	14.2	3.8	0.7	1.1	71.3	48.4
18	21.8	24.4	2.6	105.4	50.4	548.4	12.0	12.0	3.4	0.6	1.0	68.6	32.1
27	27.6	34.0	6.4	142.4	66.8	681.8	15.0	6.8	3.8	0.7	0.6	55.0	19.8
39	28.8	31.4	2.6	130.0	73.4	627.2	12.8	11.4	3.4	0.6	1.0	56.2	31.2
63	23.1	26.6	3.5	125.3	43.6	533.9	13.0	8.8	3.5	0.6	0.8	71.4	22.3
65	22.6	26.2	3.6	129.6	63.1	638.8	11.8	11.6	3.4	0.5	0.9	71.8	29.8
Mean	24.8	28.5	3.7	126.5	59.5	606.0	12.9	10.1	3.5	0.6	0.9	64.6	27.0

‡Days after June 30.

tionately to a correlation coefficient between two traits, a selected sample of lines could give lower r-values than would a random sample; however, the Gama and Hallauer (1977) study, in which random lines were used, does not support this statement.

The conclusion that may be drawn from this study is that visual selection of inbred lines is likely to be just as effective as a system of early testing. The breeder should select for those highly heritable traits in the inbred lines that will be expressed in the hybrid combinations; e.g., plant and ear height, maturity, disease and insect resistance, and grain quality. Selection for simultaneous silk emergence and pollen shed will assist in the production of lines that resist barrenness in hybrid combinations. This may be accomplished either by developing lines in a high plant density or by selecting two-eared types in a lower plant density. Because stalk quality seems to be an inherent problem with two-eared types, the breeder may need to devote considerable effort to the improvement of stalk quality in source populations that have high gene frequencies for the two-eared traits.

Inbred lines used to produce single crosses for commercial use must have high seed yield and good pollen production. Effective visual selection for inbred-line traits in the segregating progenies usually will not extend beyond three generations of inbreeding. The identification of lines with high hybrid performance will have to be ascertained by thorough evaluation of testcrosses, which can be started as early as the S_3 generation, perhaps as early as the S_2 in some situations, and certainly not later than the S_4. Choice of the tester will be the decision of the breeder, but it seems logical to move directly into hybrid evaluation with lines already in the program because the first use of new lines will be with established parents.

The hybrid yield potential of an inbred line is determined by the genotype of the S_0 plant from which it is developed; therefore, hybrid yield gains will not be realized unless the source populations have high frequencies for those genes that will increase grain yield. Results from several studies published in recent years (Moll and Stuber, 1971; Burton et al., 1971; Eberhart et al., 1973; Russell et al., 1973; Hallauer, 1973; Horner et al., 1976; Walejko and Russell, 1977) show that much improvement in population performance can be accomplished by recurrent selection. Consequently, populations improved by recurrent selection procedures should be the best source from which to begin the development of new inbred lines.

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