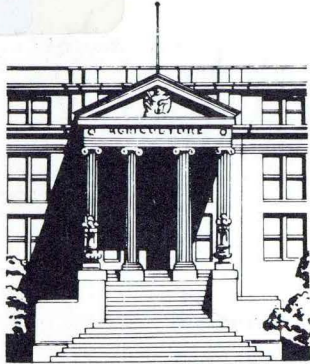


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**Selection in *Zea mays* L.  
by Inbred Line Appearance and Testcross Performance  
in Low and High Plant Densities**

by W. A. Russell and A. H. Teich

Department of Agronomy

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## SUMMARY

The purposes of this study were:

1. to test the hypothesis that lines selected by performance in high-population densities will be superior at both low- and high-population densities, but that lines selected in low-population densities may not be superior in high-population densities;
2. to compare the effectiveness of visual selection and selection by testcross performance for the production of lines superior as inbreds and in hybrid combination; and
3. to observe the pattern of ear-shoot elongation of the selected lines during the two weeks before silking and to relate these patterns to selection methods and combining abilities.

The lines under study were selected from  $F_2$  of M14xC103 by four methods: selection by testcross performance in low- and high-population rates, designated as groups 1 and 2, respectively, with group 0 representing three lines superior at both rates; and selection by visual evaluation of inbred lines in the low- and high-population rates, groups 3 and 4, respectively.

Testcrosses of the 61 selected lines were evaluated as group composites planted at five population levels at five locations in 1964 and 1965. Individual testcrosses were studied at three population levels at three locations in 1964 and 1965. Inbred lines were evaluated at one site, groups 3 and 4 in 1963, and all groups in 1964 and 1965, at two population levels. Hybrid characters studied included grain yield and moisture at harvest, incidence of barren stalks, root and stalk lodging. Inbred characters studied included grain yield and moisture at harvest, date of anthesis, plant height, incidence of barren stalks, root and stalk lodging and developmental patterns of the first and second ears for two weeks before silk emergence.

In the hybrid composite experiments, there were no interactions with population levels for the comparisons of group 1 vs. 2, group 3 vs. 4 and group 0 vs. 1, 2, 3, 4. In the experiments of individual testcrosses, only the comparison of group 0 vs. 1, 2, 3, 4 had an interaction with population levels. These results indicated that selection at low- or high-population density produced lines with similar response to population levels. It was evident in both sets of experiments, however, that the groups selected in dense populations were always superior to the groups selected in low populations when compared at the highest planting rates, although this was not necessarily true at the other rates. Furthermore, the negative regression coefficients were smaller for the groups selected in dense populations, indicating a lower yield reduction under population stress for lines selected for performance in dense populations.

A comparison of group means indicated that selection for combining ability was effective in groups 0, 1, 2 and 4 but not for group 3 when compared with (M14xC103) x tester. Group 0 was superior to groups 1, 2, 3 and 4, and the lines in group 0 showed less interaction with environments. These results may be a sampling phenomenon, but they may mean that more extensive evaluation of the lines in group 0 have resulted in higher yielding genotypes that give more stability of performance. The group among-line variances indicated wider variability within the visually selected groups because of higher frequencies of extreme lines inferior and superior to the mean. There

were 21 selections with testcross performance superior to the testcross of M14xC103. The incidence of barren stalks was an important factor in testcross yields at high plant densities. Group values for root- and stalk-lodged plants showed no important differences.

Inbred grain yields of groups 3 and 4 were superior to yields of groups 1 and 2. Groups 1 and 2 were similar, but group 4 was superior to group 3, and group 0 was equal to group 4. All groups were superior to C103 and the mean of the parents, but none was superior to M14. Sixteen lines from the following groups yielded more than M14: group 0, one; group 1, one; group 2, two; group 3, five; and group 4, seven. The among-lines mean squares for all groups, except 0, indicated significant variability within the groups and the wisdom of individual line evaluations in addition to group comparisons. The among-lines variances for all groups, except 0, interacted with rates, reflecting the individuality of line response to rates. The incidence of barren stalks at the high-population densities was an important factor in inbred yields. Under drouth conditions at anthesis in 1965, there was a strong association between barrenness and delay of silk emergence relative to pollen shedding.

The estimated components of variance for error in inbred grain yield increased from a planting rate of 12,000 to 24,000 for all groups. The component for among lines increased relatively more than the error component from rate 12,000 to rate 24,000 for all except group 2 in which the increases were similar. The line x year component increased from rate 12,000 to rate 24,000 for all except group 3. Heritability values at rates 12,000 and 24,000 were similar for groups 1, 2 and 4, but group 3 had a greater heritability value at rate 24,000 than at rate 12,000.

Group means for plant height were greater than for M14 but less than for C103. Groups 0, 1, 2 and 4 had similar values, but group 3 was significantly shorter. There were individual lines shorter than M14 and taller than C103. There were individual lines similar to M14 and C103 for root and stalk strength, but, except for greater root lodging in group 0, group differences for these characteristics were insignificant.

The growth rate of the top two ears during the 2-week period before silk emergence closely approximated a semilogarithmic curve, log ear length versus time. Groups 0, 3 and 4 had higher growth rates than did groups 1 and 2, but top ear lengths were similar, indicating earlier growth in groups 1 and 2. Groups 3 and 4 had longer second ears than did groups 1 and 2; group 0 had the longest second ears. The five lines with the highest combining ability were above average in growth rate for both cobs, but the five lines with the lowest combining ability were below average in growth rate for both cobs. The greatest differences were with the second cobs. Second-ear growth rate and its length at silking are gauges of inbred vigor and are positively associated with combining ability.

Selection by visual evaluation of inbred line performance in dense stands was at least as effective as selection by extensive testcrossing, and far more efficient. Further evaluation of breeding methods may find that the effort expended for measurement of general combining ability by topcross tests may be partly or completely replaced by inbred line performance, at a much lower cost.



# Selection in *Zea mays* L. by Inbred Line Appearance and Testcross Performance in Low and High Plant Densities<sup>1</sup>

by W. A. Russell and A. H. Teich<sup>2</sup>

The development of inbred lines and the search for their best hybrid combinations are the main bases of corn improvement in the United States. The most commonly used method for inbred development is to enforce self fertilization for several generations while practicing visual selection for the more highly heritable characteristics. During these generations, surviving stocks maintained on an ear-to-row basis become highly homozygous and highly homogeneous. Because evaluation for combining ability by using testcross procedures is expensive, it is usually delayed until after three to five generations of visual selection. Visual selection for combining ability among inbred progenies is rarely emphasized because of the commonly held opinion that it is relatively ineffective. Regardless of the effectiveness of visual selection, total genetic variability will be reduced following each selection cycle, according to the principle that the variability of a sample is less than the variability of a population. If selection is effective, the reduction will be even greater because of the removal of undesired genes, but the mean of the selected lines will exceed the mean of the original population.

Early testing, as proposed by Jenkins (1935), takes advantage of evaluation for combining ability in the  $S_0$  generation of a maize population, or the  $F_2$  of a hybrid, before genes have been eliminated by selection and, therefore, when the genetic variability among individuals is at a maximum. Superior germ plasm, identified by early testing, need not face the hazard of several generations of random sampling as in visual selection. However, the considerable expense of testing restricts the size and, therefore, the genetic base of the original population.

Visual selection within and among progenies during successive generations of inbreeding will decrease genetic variability, but this is not detrimental provided that the genes retained result in population or hybrid improvement. Visual selection need not be as productive as early testing to be more efficient than early testing because efficiency is a function of genetic advance and cost. The lower cost of visual selection allows a larger sample to be taken from the base population, with the consequently greater opportunity to obtain the desired genotypes. The problem is to apply effective, but inexpensive, selection pressures that will assist in the isolation of the desired genotypes.

A second problem in the development of parental

materials is the type of environment in which to practice selection. An ideal environment should enhance the heritability of the character being selected, as in the case of disease resistance in an artificial epiphytotic. The performance of lines in the selection environment should be highly correlated with their performance across the range of environments in which the lines are to be used.

One school of thought proposes that selection for yield in hybrid combinations, or combining ability, should occur under conditions that maximize yield; i.e., a high productivity environment. An opposing school of thought suggests that, since the environment is usually suboptimum for some factor, stress is therefore the normal situation. Crops must be developed to perform under normal conditions that crops must face; i.e., stress. Because the normal variations of environment may be dampened in a selection nursery or yield plots because of better-than-normal cultural practices, or a sequence of favorable years, the selected lines may be unsuited to the average range of environmental conditions that will occur. The application of some form of stress in the selection nursery or yield trials might alleviate this situation.

(Some explanation for the meaning of stress is needed. For grain yield, stress to maize may be considered from two aspects: yield per plant and yield per unit area of field space. A corn plant has been subjected to some type of stress if its grain yield is less than the maximum potential for the genotype. When considering yield per unit area, however, stress of some type has been a limiting factor if the maximum grain yield per unit area has not been realized for the genotype. Some of these stress factors may be: number of plants and limited supplies of nutrients, water and light. If the individual plant is not under stress for grain production, maximum grain yield per unit area will not be obtained; or, if maximum grain yield per acre is obtained, the individual plant is under stress and will not produce its maximum potential.)

The purpose of this research was to compare inbred performance and combining abilities, as expressed by grain yields, of lines developed by two methods: (1) visual selection within and among ear-to-row progenies during successive inbreeding generations and (2) selection within and among ear-to-row progenies based upon testcross performance. Each method of selection was done under two regimes: low and high plant populations. The hypothesis was that inbred lines selected because of superior performance in high-population densities will be superior in both low- and high-population densities, but that lines selected because of superior performance at low-population densities will not necessarily be superior in high-population densities.

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## REVIEW OF LITERATURE

Jenkins (1935) studied the effectiveness of visual selection by evaluating topcross yields of seven lines from Iodent and five lines from Lancaster for progenies in generations  $S_2$  to  $S_8$ , omitting  $S_7$ . Each line in each generation was represented by a selected ear and a discarded sib. Results of the tests with the Iodent lines indicated that, for the first and second generations of inbreeding, the average yield for the selected progenies was significantly greater than for the discarded sibs. For generations after the second in Iodent and for all generations in Lancaster, average differences of topcross yields for the selected and discarded sibs were not significantly different, but there was a consistent difference in favor of the selected progenies. Since no significant linear trend in the yield data was obtained, Jenkins concluded that the inbred lines acquired their individuality as parents of topcrosses very early in the inbreeding process and remained relatively stable thereafter.

Richey (1945) reanalyzed Jenkins' data on the theory that selection might have been effective in some families and ineffective in others and that averaging over families could have obscured these results. In his reanalysis of individual families by two-generation periods, he did reveal some lack of correspondence between early and later generation performance. Later, Richey (1947) noted that inbred performance of  $S_3$  or  $S_4$  lines was about as good a criterion of combining ability as topcross performance and had a much lower cost.

Sprague and Miller (1952), in studying the effect of visual selection during inbreeding of  $S_0$ - $S_4$  generations in two sets of corn progenies, found no change in combining ability of the selections. Wellhausen and Wortman (1954) found that visual selection during further inbreeding in selected  $S_1$  lines resulted in a small positive gain in combining ability, but only when the lines were tested in hybrid combinations under conditions similar to those under which the inbreeding and selecting were done. The gain was greater in lines from unadapted sources. Data presented by Osler, Wellhausen and Palacios (1958) supported the efficacy of visual selection on combining ability. They also found that the selection for yield in hybrid combinations was more effective in introduced than in local, well-adapted varieties.

Two of the most comprehensive studies for using inbred characters to predict hybrid performance were reported by Jenkins (1929) and Hayes and Johnson (1939). Jenkins studied 18 inbred characters, but found only a few with any predictive value for hybrid yield: plant height, number of nodes, number of nodes below the ear and inbred grain yield. The multiple correlation of these characters with yield in single crosses was  $R = +0.42$ . Because differences among single crosses involve a maximum of nonadditive gene effects, but differences among inbred parents involve only additive gene effects, this multiple correlation would be a minimal value.

Hayes and Johnson (1939) calculated correlations between characters of inbred lines and their yields in topcrosses with an open-pollinated variety. In an in-

bred-variety cross, additive gene action is of greater relative importance than nonadditive gene action because of the great genetic variability of the gametes from the variety. These authors, using 12 inbred vigor characters, most of which were used in the previous study by Jenkins, found a multiple correlation value of  $R = +0.666$ .

The relationship between  $S_1$  yield performance and general combining ability is relevant to the visual selection controversy. If there is a positive relationship between  $S_1$  yield and general combining ability and if visual selection can be used effectively to pick high-yielding inbred progenies, then visual selection for inbred yield can be used in the development of high-combining inbred lines. Kwon and Torrie (1964) found significant correlations between visual scores and actual yields in two soybean populations. Their expected gain by using visual selection was 50 percent as efficient as using plot yields.

Genter (1963) suggested that, if heterosis results primarily from "additive and dominant gene effects, progeny performance in early generation inbred lines should evaluate their combining abilities better than testcrosses." He cited several authors who found correlations between  $S_1$  performance and topcross performance, ranging from  $r = +0.59$  to  $+0.86$  for grain yield.

Genter and Alexander (1962) reported correlations between  $S_1$  and testcross performance as close as correlations between two sets of three-way crosses of the  $S_1$  lines. Yields of a synthetic of  $S_1$  performance-derived lines were superior to yields of a synthetic of testcross-derived lines in two consecutive cycles. The advantage of  $S_1$  over testcross performance was caused by the masking effect of testers.

Lonnquist and Lindsey (1964) compared  $S_1$  line performance versus topcross performance. Their three highest yielding  $S_1$ -derived lines when tested in topcrosses yielded 59.5 bushels per acre, compared with the three topcross-selected lines that yielded 66.9 bushels per acre. Although there was a greater range of expression in the  $S_1$  yields, there was also a greater genotype  $\times$  environment interaction.

Early testing of corn inbred lines in testcross combinations has proved effective in identifying favorable genotypes for continued inbreeding and selection. Sprague (1946) evaluated 167  $S_0$  plants of Stiff Stalk Synthetic in topcrosses with double cross Ia13. Individual plants in  $S_1$  lines from a seriated sample based on the  $S_0$  hybrid performance were tested in topcrosses with the Ia13 tester. The correlation for yield performance of the two generations was  $+0.85$ .

Lonnquist (1950) used topcross performance to obtain divergent selection for high and low combining ability from  $S_1$  to  $S_4$  generations of lines from Krug Yellow Dent. Selection among  $S_1$  lines was continued in two directions from the  $S_2$ ,  $S_3$  and  $S_4$  generations. Topcross yields of the selected high and low lines indicated that selection for high and low combining ability in successive generations was successful. He concluded that selection based upon topcross performance could greatly modify the combining ability of  $S_1$  lines in subsequent selfed generations and that early testing of  $S_1$  lines provided a better sample of



material in which to inbreed than a random sample from the same population.

The literature appears barren of information on the effectiveness of visual selection on the improvement for yield of corn inbred lines per se. For critical information, one must turn to autogamous crops, which may be considered analogous to inbred lines of corn. This analogy may be weakened if, in the early segregating generations, nonadditive gene action in corn is greater than in autogamous crops.

Weiss, Weber and Kalton (1947) and Kalton (1948) studied early generation testing in soybean crosses as a means to provide information before the  $F_4$  generation on the potential yielding ability of subsequent generations. In both studies, there was a lack of positive association between mean yields of pedigreed lines in  $F_3$  and their descendant progenies in  $F_4$ . Differences in environmental effects between seasons were reasoned important among causes for lack of association. The relationship between early and later generations was more consistent for other agronomic characters such as plant height, maturity and lodging.

In the  $F_3$  of a barley variety cross, Atkins (1964) selected 25 good plants, 25 random plants and 25 poor plants on the basis of phenotype. When placed in yield trials in the  $F_5$ ,  $F_6$  and  $F_7$ , they yielded in the expected descending order of good, random and poor. Because the difference between the good and poor lines, although significant, was less than 1 bushel per acre, and the difference between the good and random lines was only 39 pounds per acre, Atkins (1964) concluded that visual selection on a single plant basis was not practical, except perhaps in the identification of low-yielding lines.

Frey (1962) found visual selection for grain yield ineffective when based upon single oat plants, but effective when based upon progeny rows. Hanson, Leffel and Johnson (1962), working with soybeans, found that observers were capable of visual discrimination of extremes, principally the poor-yielding plots. They concluded that, unless a breeder is dealing with a cross that gives an extreme range of progenies, visual discrimination should be used primarily to discard poor-yielding genotypes rather than to select superior ones.

The choice of environment in which to practice selection is a problem mainly because of genotype x environment interaction and variations of heritabilities in different environments. The former is important because it measures the failure of genotypes to have the same relative performance in different environments, causing an obvious problem in selecting and discarding. The second problem arises because the breeder normally desires to select in an environment that maximizes the heritability of the character he wishes to improve.

In a study of rice genotype interactions with planting date and plant density, Kariya and Yamamoto (1963) found no interaction of varietal yields with planting date, but varietal yields did interact with planting density. Heritabilities for the following characters decreased with increasing plant density: panicle length, number of panicles, panicle weight and heading

date. They concluded that it is advantageous to select early generations in low densities.

Huber (1956), in a study of corn inbreds in hybrid combination for efficiency of water use at different population densities, found no obvious differences at low populations, but at high populations, corn hybrids differed widely in their efficiency of water use.

Light effects on different corn genotypes were studied by Knipmeyer et al. (1962). They found that, as population was increased, light became a limiting factor in yield potential, and genotypes varied in their response to different light intensities. Earley et al. (1966) found that two corn single crosses, WF9xC103 and Hy2x0h41, responded differently for grain yield when light was artificially restricted. Single cross WF9xC103 had greater yield reductions than did Hy2x0h41 when light was restricted by artificial shading of the plants.

Frey (1964) selected one group of oat lines for several generations on a gravelly, eroded knoll, while a second group was selected in the adjacent fertile area of deposition. Although there were no significant yield differences attributed to selection methods in subsequent yield trials, the mean square for strains x environments suggested a superior yield stability for those lines selected under conditions of high fertility.

Gotoh and Osanai (1959b), selecting under three fertility levels, obtained superior wheat lines more frequently in the low-fertility selection nursery, and these had a wider adaptation to fertilizer levels. Heritability for yield was higher in the low-fertility nursery. Gotoh and Osanai (1959a) also found that selection of wheat progenies under different densities had higher efficiency in wide spacing because of increased phenotypic variation. This was in contrast to the results of Guitard, Newman and Hoyt (1961) who found that selection from space-planted, early generation hybrid wheat, oats or barley was less efficient than in dense seedings.

Soybean plant competition at close spacings inflated both variability for a constant genotype and the genetic component as well, giving an extremely biased description of individual plants (Hinson and Hanson, 1962). The bias in yield for individual plants was caused by the competitive advantage of a single plant genotype, plus the competitive disadvantage of its neighbors. Evaluation of individual plants for secondary characters, such as chemical differences, was little influenced by competition.

Weber (1957) compared selection of individual soybean plants from bulk hybrid soybean populations in different plant spacings, attempting to improve yield but to maintain constant maturity. The progenies of these selections, evaluated in replicated drilled plantings, showed no yield, height or lodging differences among selections from different spacings.

Interactions of corn genotypes with population densities were studied by Rossman (1955) and Woolley, Baracco and Russell (1962). Rossman (1955) found that hybrids good at low populations were generally good at high populations but that sufficient exceptions existed to warrant testing at two population densities. Woolley, Baracco and Russell (1962) found in a diallel of four inbred lines that, in one of two experimental years, crosses had a significant interaction



with population densities, and in the other, with within-row spacing patterns, each involving change in rank of crosses.

Nine single-cross corn hybrids grown at various population and nitrogen levels by Lang, Pendleton and Dungan (1956) had hybrid x population and hybrid x nitrogen level interactions for yield. Similar studies in wheat by Pendleton and Dungan (1960) indicated differential responses to fertility and population levels, but rank remained the same. This was consistent with the findings of Lamb and Salter (1936) and Worzella (1943) who found that yield of wheat varieties did interact with fertility levels but that rank remained the same.

Ferguson (1962) studied the influence of population density on the hybrid performance of maize inbred lines by using three lines whose maximum yield was attained at 20,000 plants per acre, the low group, and three lines whose maximum yield was attained at 28,000 or more plants per acre, the high group. General and specific combining abilities were appraised in a modified diallel in a number of different planting densities.

The high group was superior at both low- and high-population densities, but the low group did well only at the low densities and suffered a decline in yield as population increased. The high group showed no yield depression up to 28,000 plants per acre, after which yield declined slightly to 32,000 plants per acre, the densest population. With a single exception, the rank of individual lines was the same from year to year and across population densities. The mean yields of low x low crosses increased from 12,000 to 24,000 plants per acre and then dropped sharply. The high x high crosses increased to 28,000 and then leveled off to 32,000. The low x high showed an interesting heterotic effect, being superior to low x low and high x high at the four highest rates.

Sass (1960) observed that the morphological differences between the two top ears in a one-ear, yellow, dent hybrid were not evident until 68 to 71 days following planting. After this, failure of second ear development was caused by factors associated with competition before and after anthesis. Sass and Loeffel (1959) found that the formation of floral organs in maize was not prevented by dense planting. Competitive pressure did not produce a marked reduction in ear elongation, ovary development or stalk elongation until 74 days after planting. Barrenness was caused by lack of silk emergence during pollen shedding.

Sowell, Ohlrogge and Nelson (1961) concluded that barrenness was caused by the competition between vegetative growth and ear shoot development for the limited resources of the plant. Compact mutants of inbred Hy were able to produce grain under conditions of population stress because of the termination of vegetative growth at an early stage of plant development. Normal Hy does not cease vegetative growth at the time of ear shoot development, and in dense populations, this results in barrenness.

Collins (1963) studied ear shoot development in inbreds C103, Hy, R71 and B60 and in the six possible single crosses among these lines. Inbreds C103 and Hy produce one harvestable ear, whereas R71

and B60 usually produce two harvestable ears. The single-ear inbreds and their single cross showed a retarded growth rate of the second ear, which became evident about 9 days before silk emergence. These genotypes did not produce second ears. By contrast, the second-ear development of R71, B60 and their single cross was similar to the top ear, and these genotypes usually produced a second ear. He concluded from these data that the degree of second-ear development in this early stage is an aid to detecting potential two-ear types, particularly if a harvestable second ear is not produced because of some unfavorable climatic condition.

Recent studies in the Iowa State University corn breeding research program (unpublished data) have shown a negative association between the potential number of ears of the parent lines and degree of barrenness in hybrid combinations when tested at high plant densities. The association between yield and percentage barrenness at high stand level was negative and highly significant.

Collins and Russell (1965) presented additional data on the development of the second ear in single-cross hybrids of Corn Belt single-ear and two-ear inbreds. They postulated that selection for second-ear development may be valuable in selection for stability of production.

## MATERIALS AND METHODS

### Derivation of Experimental Materials

The inbred lines used in this study were developed from an  $F_2$  population of M14xC103. Previous studies in the Iowa State University corn breeding program (unpublished data) indicated that single crosses with M14 as one parent were not as adversely affected by dense stands as were single crosses with C103 as one parent. C103 single crosses frequently showed a high incidence of barren stalks in dense stands. Woolley, Baracco and Russell (1962) published data that confirmed the earlier unpublished results.

In a nursery planted at 12,000 plants per acre in 1955, 138  $F_2$  plants were selected for self-pollination and testcrossing to WF9xI205, a tester, which in previous experiments, was intermediate between M14 and C103 single crosses in its response across population densities. At harvest, the selfed and testcross seed of 95  $F_2$  plants were retained for evaluation. Testcrosses for this generation were evaluated at one location for 2 years and for two subsequent generations at two locations for 2 years. Plot size was 1/392 of an acre, with three replications at each site. For precision of stand, plots were seeded heavily and thinned to the required population density.

The testcross progenies of the  $F_2$  generation and of M14, C103 and M14xC103 were grown in yield trials at rates of 16,000 plants per acre and 24,000 plants per acre. Testcrosses of the  $F_3$  and  $F_4$  generations were tested in the rates at which the previous generation had been tested and judged superior. For example, if a particular  $F_2$  testcross was superior at rate 24,000 but inferior at rate 16,000, the testcrosses of the  $F_3$  from that  $F_2$  were tested only at rate 24,000.



Testcrosses of some  $F_2$  plants performed well at both rates, so the testcrosses of their  $F_3$  plants were tested at both rates. Testcrossing of the  $F_3$  and  $F_4$  generations was performed by the selection of one to three plants per progeny row, selfing and crossing to the tester. A progeny row in the breeding nursery consisted of 16 plants at a population density of 12,000 plants per acre. There was no elimination of entire progeny rows in the  $F_3$  and  $F_4$  generations, but individual plants were selected for general vigor and plant type. They were reselected at harvest for resistance to stalk and ear rots.

Testcross evaluations were  $F_2$  in 1956-57,  $F_3$  in 1959-60, and  $F_4$  in 1962-63. Drouth conditions in 1956 restricted grain yields, particularly at the high stand level. Late planting at one location in 1959 limited grain yields, again more severely at the high stand level. Tests were conducted on soils with a high productive capacity, and fertilizer was applied as recommended for the sites. Nutrient deficiencies were not evident in any of the experiments, but availability of nutrients may have been too limited in some sites to permit maximum yields at the higher plant density.

It is obvious that with evaluation in 10 environments, considerable variation in environmental conditions was encountered. Comparisons between the two stand levels, although not strictly valid because they were separate experiments, may still be useful because the two experiments at a site were always in adjacent areas. Mean yields for rates 16,000 and 24,000 were similar in four environments, rate 16,000 exceeded rate 24,000 in five environments and rate 24,000 exceeded rate 16,000 in only one environment. The estimated variance component for entries was higher at rate 24,000 than at rate 16,000 in all except one environment. The moisture stress at rate 16,000 in one location may have been as severe as the moisture stress at rate 24,000 in a different location. In general, yield results indicated that selection, not only favored M14 germ plasm at rate 24,000 but occasionally at rate 16,000 as well. Yields for testcrosses of M14 and C103 suggest that some environments favored selection of C103 germ plasm.

Parents of testcrosses were usually retained for further evaluation in the next generation if grain yields of the testcrosses were equal to or more than the checks. There was some selection for resistance to root and stalk lodging and maturity earlier than C103. Where more than one testcross per  $F_3$  or  $F_4$  progeny was evaluated, not more than one parent offspring was retained for evaluation in the next generation.

Of the 31 testcrosses of  $F_4$  plants evaluated at rate 16,000 in 1962-63, 52 percent exceeded (M14xC103)(WF9xI205) by more than one L.S.D. at the 5-percent level of probability. In the first test of  $F_2$  plants at rate 16,000, 1956-57, only 9 percent of the testcrosses exceeded (M14xC103)(WF9xI205). Of the 32 testcrosses of  $F_4$  plants evaluated at rate 24,000 in 1962-63, 63 percent exceeded (M14xC103)(WF9xI205) by more than one L.S.D. at the 5-percent level of probability. In the first test of  $F_2$  plants at rate 24,000, 1956-57, none of the testcrosses exceeded (M14xC103)(WF9xI205). Although these are not precise comparisons, they do give an indication of

the definite progress obtained in this area.

Twenty-nine lines survived the three generations of testing: 16 lines within each group, with three lines common to both groups. Within a group of 16 lines, each line had a different  $F_2$  ancestor.  $F_5$  seed of the selections were planted as ear-to-row progenies in 1963, and plants were self-pollinated to provide seed for inbred line tests to be conducted in 1964-65. Also, these  $F_5$  lines were crossed to testers for comprehensive yield trials.

A second group of inbred lines was developed from M14xC103 by using phenotypic appearance of the plants as the only criterion of selection. The source material was the same 95  $F_2$  plants selected when the first testcrosses were made in 1955. Progeny of the  $F_2$  selections,  $F_3$ , were planted ear-to-row in a breeding nursery at rates of 12,000 and 24,000 plants per acre. A plot of the first rate contained 25 plants, one per hill, and at the second rate, 50 plants, two per hill, where the stand was perfect. At rate 12,000, all plants with good phenotype were eligible for selection, but at rate 24,000, only plants in two-plant hills and bordered were eligible. Because of missing hills or one-plant hills in the rate-24,000 rows, the number of plants actually eligible for selection usually was not appreciably greater than in rate-12,000 rows. For three generations, at pollinating time and harvest, selection was practiced among and within rows for general vigor, desirable plant and ear types, disease resistance and simultaneous release of pollen and silk emergence. The last character was considered important because inbreds that have delayed silk emergence under stress transmit this behavior to their progeny, resulting in some degree of barrenness. In the  $F_3$  generation, barrenness or delayed silking at rate 24,000 eliminated many plants. Seed of a plant selected was planted at the same rate in the following generation. In the  $F_6$  generation, selection was only among rows, and seed of selfed ears within a progeny was bulked. The  $F_7$  lines were grown at rate 12,000 in 1963 for an increase of inbred seed and for crossing to testers for evaluation of combining ability. The 16 lines within each group each descended from a different  $F_2$  plant.

The first comprehensive evaluation of all selected lines was made in 1964 when the testcrosses were studied at five locations and inbred lines per se were studied at one location. The inbred selections, M14, C103 and M14xC103, had been crossed to WF9xI205 and Ia4810. Single-cross WF9xI205 was used because it was the tester used in the derivation of the selections by testcross procedure. Ia4810, an unrelated double-cross tester, was expected to give a satisfactory measure of general combining ability.

To simplify the presentation, group numbers will be used:

Group 0 - lines selected by testcross performance at both rates;

Groups 1 and 2 - lines selected by testcross performance in low and high rates, respectively;

Groups 3 and 4 - lines selected by visual discrimination in low and high rates, respectively;

Groups 5, 6 and 7 - testcrosses of M14, C103 and M14xC103, respectively;



T<sub>1</sub> and T<sub>2</sub> - WF9xI205 and Ia4810 testers, respectively.

The inbred selections were evaluated by testcross performance in two sets of hybrid trials. In one set, all testcrosses within one selection method and a common tester were bulked as a single entry; i.e., seed from all lines selected by testcross performance at low stand, group 1, and crossed to WF9xI205, 16 testcrosses, were bulked to produce a single entry. There were eight composites because four groups of selections were crossed to two testers. Each of the testcross-derived composites contained the three lines in group 0 because they would have been selected if only a single rate had been used. The second set of hybrid trials consisted of individual lines in crosses with WF9xI205, each testcross retaining its identity. The three checks, M14, C103 and M14xC103 crossed with the same tester(s), were grown in both sets of experiments.

#### Composite Tests Field Procedures

The 14 entries in the composite trials were placed in a split-plot arrangement of a randomized complete block design. Main plots consisted of five population rates and subplots, the 14 entries. There were two replications at each of five locations.

A subplot consisted of a single row, 400 inches long and 40 inches wide. The plots were bordered only between population rates to minimize the competition of adjacent subplots at different population rates. Population rates were obtained by varying the distance between hills within the row and maintaining the number of plants at two per hill, except for the end hills which had three plants. The number of plants per plot after thinning was 30, 40, 50, 60 and 70 for the five rates. For convenience, the population levels will be referred to as rates of 12,000, 16,000, 20,000, 24,000 and 28,000 plants per acre.

The experiments were planted on soils with high productive capacity supplemented by fertility programs based on soil tests. Data obtained for each plot were: number of plants at harvest, total weight of ear corn, grain moisture, number of root- and stalk-lodged plants, number of dropped ears and number of barren stalks.

This set of experiments was repeated in 1965 at the same locations, with a few changes in procedure. The three lines common to the two testcross-derived groups of lines, group 0, were entered as separate composites, one for each tester. This increased the number of entries to 16. However, testcrosses of these lines were retained in group 1 and 2 composites so that data for the two years could be combined. Data for root and stalk lodging and dropped ears were not recorded in 1965.

#### Individual Testcrosses Field Procedures

The second set of hybrid trials had 64 entries consisting of 61 selections and three checks, M14, C103 and M14xC103, crossed to WF9xI205. The experiment was conducted at three locations in 1964 and 1965. The experimental design was a split-plot arrangement in which the whole plots were three popu-

lation levels and subplots, the testcrosses. Each whole plot had 64 subplots in an 8x8-lattice design. There were two replications at each location.

The subplots were of the same size as used in the composite experiments. Population levels were obtained as described previously, and the number of plants per plot after thinning was 30, 45 and 60 for the three rates. For convenience, the population levels will be referred to as rates of 12,000, 18,000 and 24,000 plants per acre.

Data obtained for each subplot in 1964 were: number of plants harvested, total weight of ear corn, grain moisture, number of root- and stalk-lodged plants, number of dropped ears and number of barren stalks. Similar data were recorded in 1965, except that data for root and stalk lodging and dropped ears were taken only for the 18,000 population level.

#### Composite Tests Statistical Procedures

Only the statistical analysis for data on grain yields will be presented. The ear weights per plot were converted to cwt of grain per acre at 15.5-percent moisture. The analysis of variance was in the form of a split plot, with rates as the main plots and entries as subplots. Replications, rates, testers and entries were considered as fixed variables, and locations and years were equated to environments, thus giving 10 random environments.

In the analysis of variance, the degrees of freedom and sums of squares for entries and entry interactions were partitioned into the orthogonal components that were most relevant to the study; i.e., groups 0, 1, 2, 3, 4 vs. 5, 6, 7; group 0 vs. 1, 2, 3, 4; groups 1, 2 vs. 3, 4; group 1 vs. 2; group 3 vs. 4; 5, 6 vs. 7; and 5 vs. 6. Group 0 was not available for 1964 or the combined analysis that included years. Population rates were equally spaced independent variables. Degrees of freedom and sums of squares for rates and interactions involving rates were partitioned into rates linear, rates quadratic, and remainder by the method outlined by LeClerg (1957). The cubic and quartic components were not considered of biological or agronomic importance. The use of most error terms was justified by the expected mean squares, but in the instances of the orthogonal comparisons and subdivisions of rates, the pooled interactions with locations of the complete set less one significant interaction in the partition of each of entries x locations and entries x rates linear x locations were used.

Throughout the presentation and discussion of the data, only differences significant at the 5-percent level of probability will be recognized as real differences. However, the tests of significance will not be at the exact probabilities given because Bartlett's (1937) test of homogeneity for the error b variances of the 10 environments indicated that the variances were not homogeneous. Heterogeneity of error variances was expected because previous experience with yield tests at different population rates has shown that the error values usually increase as stand densities increase. Because this behavior would be erratic among environments, it would contribute to the heterogeneity of error values.



### Individual Testcrosses Statistical Procedures

The lattice analysis was used to calculate the entry means adjusted for block differences and error mean squares for each rate according to the statistical procedures for simple lattice designs. The three simple lattices at each location were combined and treated as a split-plot experiment, using population rates as the main plots and entries as the subplots. Replications, rates and entries were considered fixed variables, and locations and years were equated to environments, thus giving six random environments. For a single environment, an average effective error mean square was calculated by pooling the errors of each rate. For the combined analysis over environments, a pooled average effective mean square was calculated in a similar manner. Bartlett's (1937) test for homogeneity had indicated that the error mean squares among environments were heterogeneous. The three population rates were equally spaced independent variables. Degrees of freedom and sums of squares for rates and interactions involving rates were partitioned into rates linear and rates quadratic by the method outlined by LeClerg (1957).

In the analysis of variance, the degrees of freedom and sums of squares for entries, entry interactions, rates and rates interactions were partitioned similarly to the procedure outlined for the composite tests. In addition to the group comparisons in entries, there are also five within-group comparisons for groups 0, 1, 2, 3 and 4. The orthogonal comparisons within entries were tested with appropriate mean squares in the orthogonal partition of entries x environments to obtain  $F$  values because most of the orthogonal comparisons in the interaction were significant. However, the orthogonal comparisons within entries x rates linear were tested by entries x rates linear x environments and entries x rates quadratic, by entries x rates quadratic x environments to obtain  $F$  values because there was only one significant second-order comparison in each case.

### Inbred Line Tests Field Procedures

The inbred lines per se were evaluated for agronomic performance in an experiment grown at one location for 3 years. A split-plot design with five replications was used in which two population rates were the main plots. Entries or inbred lines were randomized in the subplots within the main plots. In 1963, there were 38 entries: 18  $F_7$  lines in group 3, 18  $F_7$  lines in group 4, M14 and C103. In 1964 and 1965, there were 63 entries: 3  $F_6$  lines in group 0, 13  $F_6$  lines in group 1, 13  $F_6$  lines in group 2, 16  $F_8$  lines in group 3, 16  $F_8$  lines in group 4, M14 and C103.

A subplot consisted of a single, unbordered row 200 inches long and 40 inches wide, with hills spaced 13.3 inches in the row. The lower rate of 12,000 plants per acre had one plant per hill, and the higher rate of 24,000 plants per acre had two plants per hill. An extra kernel was planted per hill and thinned where necessary when the corn had reached a height of about 12 inches.

Data taken on a plot basis included number of plants at harvest, total grain weight, dates when 50

percent of the plants had shed pollen and reached silk emergence and number of barren stalks, in all three years; grain moisture in 1963 and 1964; and plant height, root and stalk lodging, and number of ears in 1964 and 1965. The ears were shelled without drying in 1963 and 1964 and after drying in 1965. Grain weights were converted to cwt per acre at 15.5-percent moisture.

### Inbred Line Tests Statistical Procedures

The analysis of variance will be presented only for the grain yields. The analysis procedures were essentially the same as already described for the testcrosses except that lattice designs were not used. Groups 0, 1 and 2 were not in the 1963 test, and M14xC103 was not an entry in any of the experiments. In the combined analysis, for the  $F$  tests involving group comparisons, the mean squares for entries x years and entries x rates x years were used as the denominator because of the low number of degrees of freedom for several of the orthogonal comparisons in these first- and second-order interactions.

Yield data of the 61 selections were analyzed by groups for each population level. Selections in group 0 were included in both groups 1 and 2 for these analyses. Estimates of variance components were calculated for lines and lines x years interaction in each analysis of variance.

### Ear Shoot Development of Inbred Lines

In 1963, 36  $F_7$  lines in groups 3 and 4, M14 and C103 were planted in an unreplicated experiment with single-row plots. The stand density was one plant per hill spaced 13.3 inches apart, or 12,000 plants per acre.

Extraction and measurement of ear shoots, or cobs, was begun 3 weeks before the anticipated date of silking and repeated approximately every second day until each line had 50 percent or more of the remaining plants in the plot showing emerged silks. The length measurements on this day were the last for that particular line.

An observation was made by taking five bordered plants from a plot, extracting the two top ear shoots from each plant and averaging the cob lengths of the five top cobs and the five second cobs, respectively. The extraction technique consisted of slitting both flat sides of the culm with a knife from crown to apex, stripping off the leaves to expose the prophylls and removing the top two prophylls. The two prophylls were opened by a longitudinal incision that exposed the cobs for measurement.

In 1964, all inbreds entered in the inbred yield trials were entered also in this experiment for the study of ear-shoot length development. The field design was a randomized block with three replications and single-row plots. In an adjacent area, M14xC103 was planted to provide a comparison of the inbreds with their single-cross progenitor, without exposing the inbreds to the superior competitive advantage of a hybrid.

In 1964, three bordered plants per replication were sampled at each observation. The final observation of each line in both years was 10 plants, or as many



as available up to 10 per replication, to make the final value as precise as possible. Using the final date of sampling for each line, 14 days earlier became day 1, 13 days earlier became day 2, etc., to provide a coded calendar based on the lines' organogeny. The data of lines of common selection method were bulked to minimize erratic trends due to small sample size.

The 1963 season was excellent for corn production, with generally adequate moisture supply. There was a shortage of soil moisture for several days in late June, but this was relieved 2 weeks before the first observations. The 1964 season was excellent from the date of planting until the termination of the experiment.

## RESULTS

### Tests of Composites

Average grain yields for each stand level at the five locations in 1964 and 1965 (table 1) show the production levels in the 10 environments (five locations in 2 years, 1964 and 1965). The highest average yields were obtained at the 16,000 population in six environments, the 20,000 population in two en-

Table 1. Grain yields for five population densities at five locations in 1964 and 1965.

Location	Yield, cwt per acre at population density (x1000)					Mean
	12	16	20	24	28	
1964						
Sheldon	55.3	56.1	54.9	50.8	46.3	52.7
Newell	63.9	69.5	69.6	62.8	59.5	65.1
Hampton	59.0	64.9	62.6	59.4	48.6	58.9
Ames	55.0	55.1	53.3	45.8	43.6	50.5
Ankeny	51.6	53.0	51.8	40.5	37.8	46.9
1965						
Sheldon	48.7	44.8	43.2	38.5	33.7	41.8
Newell	35.6	33.3	26.4	17.9	13.5	25.3
Hampton	54.8	55.4	54.1	54.1	49.7	53.6
Ames	57.1	58.1	50.6	42.0	32.4	48.1
Ankeny	65.6	73.7	75.4	63.5	57.0	67.1

Table 2. Agronomic data for four groups of selections and three checks in testcross performance, data summarized for five population levels over two testers, five locations and two years.

Composite	Yield, cwt per acre at population levels (x1000)					Mean	Regression coefficients		Percentage <sup>a</sup> grain moisture	Percentage barren stalks at population levels (x1000)	
	12	16	20	24	28		R <sub>l</sub>	R <sub>q</sub>		24	28
Group 1	55.8	58.6	55.9	49.3	42.7	52.4	-3.55	-1.63	26.2	19.6	21.8
Group 2	56.8	58.0	56.3	50.7	45.4	53.4	-3.00	-1.21	27.0	16.8	21.6
Group 3	54.8	54.5	54.0	46.4	40.7	50.1	-3.63	-1.28	26.2	17.8	24.9
Group 4	55.5	58.3	57.4	48.1	44.9	52.8	-3.15	-1.45	26.2	16.3	21.5
M14	52.9	55.6	52.7	49.0	45.0	51.0	-2.22	-1.02	25.8	14.8	17.4
C103	51.0	50.4	46.2	40.6	33.5	44.3	-4.48	-1.02	28.4	28.0	33.4
M14xC103	54.3	55.9	53.8	46.2	40.5	50.1	-3.72	-1.44	27.1	18.0	23.9
Mean	54.4	55.9	53.7	47.2	41.8	50.6	-3.39	-1.30	26.7	18.8	23.5

<sup>a</sup> Mean for all population levels.

vironments and the 12,000 population in two environments. In most environments, the yield decrease at the 24,000 and 28,000 population levels was sharp. The highest and lowest yields were obtained at Ankeny and Newell, respectively, in 1965. Drouth was responsible for the low yields at Newell in 1965. Yield levels at all locations, except Hampton in 1965, were affected by the occurrence of a drouth stress at some period during the growing season. Late planting at Hampton in 1965, along with cold weather in September, caused poor grain development. Root lodging, which occurred before grain development was complete, affected yields at Ames in 1964 and Ankeny in 1965.

Since the group 0 composite (which included three selections superior at both low- and high- population levels) was not tested as a separate entry in 1964, the data are presented in two sets; one for 1964 and 1965, with group 0 omitted, and the second for all entries over locations in 1965. The five locations and 2 years were considered as 10 random environments because we had no particular interest in the separate effects of locations and years or their interaction. Data from individual environments will not be presented except to explain certain interactions involving environments.

Yield, grain moisture and barren stalk data for testcrosses of the four composites and three checks summarized over two testers and 10 environments are presented in table 2. Similar data for the four composites and three checks with two testers are given in table 3. The combined analysis of variance for grain yields in 10 environments is shown in table 4.

Yield differences among population rates were highly significant (table 4). The highest average yield was at 16,000 plants per acre. The yield trends were not consistent among environments (table 4) as is indicated by the highly significant mean square for rates x environments.

Crosses with tester 1 yielded more than crosses with tester 2 ( $p < 0.05$ , table 3), but tester 2 responded less than tester 1 to different rates ( $p < 0.01$ ).

There were five composites of testcrosses based on the selection method to develop the inbred lines: selection by testcross performance in low- and high-population rates, designated as groups 1 and 2, respectively, with group 0 representing three lines superior at both rates; and selection by visual evaluation of



Table 3. Agronomic data for four groups of selections and three checks in testcross performance, with two testers, data summarized for five population levels over five locations and two years.

Composite	Yield, cwt per acre at population levels (x1000)						Regression coefficients		Percentage <sup>a</sup> grain moisture	Percentage barren stalks at population levels (x1000)	
	12	16	20	24	28	Mean	R <sub>l</sub>	R <sub>q</sub>		24	28
Tester 1, WF9xI205											
Group 1	57.6	59.6	58.8	51.2	43.6	54.2	-3.64	-1.85	25.9	20.1	21.6
Group 2	59.4	59.5	57.3	52.3	46.3	55.0	-3.35	-1.08	26.5	16.5	21.8
Group 3	56.9	55.3	56.5	47.9	41.9	51.7	-3.73	-1.33	25.8	17.8	23.8
Group 4	56.4	58.7	58.9	47.7	44.0	53.1	-3.56	-1.68	25.8	16.6	22.4
M14	51.6	57.9	53.2	49.7	44.0	51.3	-2.34	-1.63	25.1	14.1	17.0
C103	52.0	52.3	47.9	42.3	33.3	45.6	-4.73	-1.42	27.8	28.2	35.6
M14xC103	56.0	55.2	54.7	45.7	37.2	49.8	-4.71	-1.70	26.2	19.0	26.8
Mean	55.7	57.0	55.3	48.1	41.5	51.5	-3.72	-1.53	26.2	18.9	24.1
Tester 2, Ia4810											
Group 1	53.9	57.5	53.0	47.4	41.7	50.7	-3.46	-1.41	26.5	19.0	22.0
Group 2	54.2	56.4	55.4	49.1	44.6	51.9	-2.66	-1.34	27.5	17.0	21.4
Group 3	52.6	53.7	51.4	44.9	39.4	48.4	-3.53	-1.24	26.6	17.8	26.0
Group 4	54.7	57.8	55.8	48.5	45.7	52.5	-2.74	-1.22	26.6	16.0	20.6
M14	54.2	53.2	52.3	48.3	46.1	50.8	-2.11	-0.40	26.4	15.6	17.8
C103	50.0	48.5	44.4	38.9	33.7	43.1	-4.23	-0.63	28.9	27.9	31.2
M14xC103	52.5	56.5	52.9	46.8	43.8	50.5	-2.72	-1.18	28.0	17.0	21.0
Mean	53.2	54.8	52.2	46.3	42.1	49.7	-3.06	-1.06	27.2	18.6	22.9

<sup>a</sup> Mean for all population levels.

inbred lines in low- and high-population rates, groups 3 and 4, respectively.

Considering first the comparisons summarized over both testers in table 2, groups 1 and 2 yielded more than groups 3 and 4, group 4 yielded more than group 3, and the mean performance of groups 1, 2, 3 and 4 was greater than the mean of the checks. These differences were all highly significant (table 4). The results of significance tests for nonorthogonal comparisons of the testcross composites with the testcross of M14xC103 shown in table 5 are valid comparisons because selections in the composite testcrosses were developed from M14xC103. Testcrosses of groups 1, 2 and 4 yielded more ( $p < 0.01$ ) than testcrosses of M14xC103. Testcross yields of group 3, M14 and M14xC103 were nearly equal, but C103 testcrosses were considerably lower.

Small differences of performance for the entries between the testers are worth comment (table 3). Whereas groups 1 and 2 yielded more than groups 3 and 4 with tester WF9xI205, the difference of groups 1 and 2 with groups 3 and 4 was negligible with tester Ia4810. Group 2 had the highest yield with WF9xI205, but group 4 had the highest yield with Ia4810. If there has been effective selection in groups 1 and 2 for specific combining ability with WF9xI205, then the results were as one should expect. The difference between selections and checks was less in crosses with Ia4810 than with WF9xI205, and this resulted in the significant interaction for 1, 2, 3, 4 vs. 5, 6, 7 x testers. Nonorthogonal comparisons in table 5 show yield differences of groups 1 and 2 with M14xC103 ( $p < 0.01$ ) when the tester was WF9xI205, but no differences in comparisons with M14xC103 when the tester was Ia4810.

The only entry comparison that interacted with environments was 5 vs. 6 because, at the higher populations, there was a much greater decrease in yield for C103 testcrosses than for M14 testcrosses. Mean yields for locations ranged from a low of 25.3 cwt per acre at Newell in 1965 to a high of 67.1 cwt per acre at Ankeny in 1965, but this large difference in environments had little effect on the relative performances of the groups. A significant mean square for 5 vs. 6 x environments was caused by a higher yield for C103 testcrosses than for M14 testcrosses at only one environment, Ankeny in 1965. There was much less root lodging for C103 testcrosses than for M14 testcrosses at this site, and the lodging occurred early enough in the season to affect grain development.

The interaction of most interest in the study was entries x rates because of methods used to select the lines from M14xC103. This interaction was highly significant only because of the comparison of M14 vs. C103 x rates linear. C103 and M14 testcrosses had nearly equal yields at rate 12,000, but from rate 12,000 to rate 28,000, the decrease was 17.5 cwt for C103 and 7.9 cwt for M14. The differences between C103 and M14 crosses were not consistent among the 10 environments as was indicated by the highly significant mean square for 5 vs. 6 x rates linear x environments.

Yield differences between the high- and low-population selections were greater at the higher stands than at the lower stands. The differences in yield for the high- and low-selection groups were as one would expect on the basis of procedures used in developing the selections. Differences were not great enough to be statistically significant. In spite of the wide range of



Table 4. Analysis of variance for grain yields of composite testcrosses and checks at five population densities, in five locations for 1964 and 1965, combined.

Source	D.F.	Mean squares
Environments (En)	9	20,925.84**
Replications in Environments	10	215.62
Rates (R)	4	9,903.48**
Linear (R <sub>l</sub> )	1	32,275.59**
Quadratic (R <sub>q</sub> )	1	6,547.55**
Remainder	2	395.40
Rates x Environments	36	330.54**
Error (b)	40	130.30
Testers (T)	1	1,121.08*
Testers x Rates	4	146.84**
Testers x Environments	9	158.88**
Testers x Rates x Environments	36	34.10
Entries (E)	6	1,879.96**
1,2,3,4 vs. 5,6,7	1	4,668.90**
1,2 vs. 3,4	1	447.75**
1 vs. 2	1	100.40
3 vs. 4	1	761.48**
5,6 vs. 7	1	800.82**
5 vs. 6	1	4,500.40**
Entries x Testers	6	140.35
1,2,3,4 vs. 5,6,7 x T	1	309.24*
1,2 vs. 3,4 x T	1	83.27
1 vs. 2 x T	1	5.86
3 vs. 4 x T	1	177.02
5,6 vs. 7 x T	1	162.14
5 vs. 6 x T	1	104.55
Entries x Rates	24	74.07**
Entries x Rates (linear)	6	195.39**
1,2,3,4 vs. 5,6,7 x R <sub>l</sub>	1	13.59
1,2 vs. 3,4 x R <sub>l</sub>	1	5.32
1 vs. 2 x R <sub>l</sub>	1	58.05
3 vs. 4 x R <sub>l</sub>	1	45.41
5,6 vs. 7 x R <sub>l</sub>	1	34.32
5 vs. 6 x R <sub>l</sub>	1	1,015.62*
Entries x Rates (quadratic)	6	29.84
Entries x Rates (remainder)	12	35.53
Entries x Environments	54	86.99**
1,2,3,4 vs. 5,6,7 x En	9	58.71
1,2 vs. 3,4 x En	9	27.37
1 vs. 2 x En	9	19.96
3 vs. 4 x En	9	33.47
5,6 vs. 7 x En	9	61.56
5 vs. 6 x En	9	320.88**
Entries x Rates x Environments	216	38.60
E x R <sub>l</sub> x En	54	42.87
E x R <sub>q</sub> x En	54	30.18
E x R x En (remainder)	108	40.67
Entries x Testers x Rates	24	35.79
Entries x Testers x Environments	54	70.78**
Entries x Testers x Rates x Environments	216	28.95
Error (c)	650	32.51

\*Significant at the 5% level.

\*\*Significant at the 1% level.

Table 5. Results of significance tests for nonorthogonal comparisons of groups of testcrosses with testcrosses of M14xC103.

	Ten environments, 1964-65				
	Group 1	Group 2	Group 3	Group 4	
M14xC103 - T <sub>1</sub> and T <sub>2</sub>	**	**	N.S.	**	
M14xC103 - T <sub>1</sub>	**	**	N.S.	**	
M14xC103 - T <sub>2</sub>	N.S.	N.S.	N.S.	N.S.	
	Five environments, 1965				
	Group 0	Group 1	Group 2	Group 3	Group 4
M14xC103 - T <sub>1</sub> and T <sub>2</sub>	**	N.S.	**	N.S.	*
M14xC103 - T <sub>1</sub>	**	**	**	*	**
M14xC103 - T <sub>2</sub>	**	N.S.	N.S.	*	N.S.

\*Significant at the 5% level.

\*\*Significant at the 1% level.

N.S. Not significant.

yields among the 10 environments, the interaction of entries x rates linear x environments was not significant.

The second sets of data presented in tables 6 and 7 give the performance for group 0 along with the other entries. Group 0 included the testcrosses of the three selections selected on the basis of testcross performance at both high- and low-stand levels. The combined analysis of variance for grain yields in five environments is shown in table 8. As an average of performance with both testers, group 0 has yielded more (p<0.01) than the average for the other groups. The selections in group 0 were in groups 1 and 2, so it is obvious that these latter groups would have yielded less if the three selections had not been included. Group 0 has yielded more (p<0.01) than the testcrosses of M14xC103 (table 5) and was the only composite to yield more than M14xC103 with tester Ia4810; group 3 actually yielded less than M14xC103 with tester Ia4810. Testcrosses of the selections in group 0 had higher mean yields than the other groups because of higher yields at all rates, particularly at 16,000 and 20,000 population levels. Differences in linear trends among the groups and checks were not significant.

The percentage of barren stalks was similar for all entries except the testcrosses of C103, which were considerably higher. Testcrosses in group 3 appeared the most susceptible to barrenness, and testcrosses of M14 had the least barrenness. Yields of C103 testcrosses at high-stand levels were limited because of the high number of barren stalks in most of the environments.

If grain moisture content is used as a criterion of maturity, the selections as groups were later than M14 but earlier than C103 (table 6). The selections in group 0 were lower in grain moisture than M14. The grain moisture of the groups was less than the grain moisture of the testcrosses of M14xC103; thus, there was some selection toward the earlier parent, M14.

#### Tests of Individual Testcrosses

Crosses of M14, C103, M14xC103 and 61 selections with WF9xI205 were evaluated in three population levels at three locations in 1964 and 1965. The 61 selections were divided into five groups based on breeding procedures for development as described earl-



Table 6. Agronomic data for five groups of selections and three checks in testcross performance, data summarized for five population levels over two testers and five locations in 1965.

Composite	Yield, cwt per acre at population levels (x1000)					Mean	Regression coefficients		Percentage <sup>a</sup> grain moisture	Percentage barren stalks at population levels (x1000)	
	12	16	20	24	28		R <sub>I</sub>	R <sub>Q</sub>		24	28
Group 0	55.4	60.4	55.8	48.0	43.0	52.5	-3.73	-1.65	28.2	25.7	32.5
Group 1	53.7	54.6	51.5	42.5	37.6	48.0	-4.43	-1.24	28.8	32.2	34.4
Group 2	54.0	56.1	52.0	45.9	40.3	49.7	-3.74	-1.23	29.8	25.7	36.6
Group 3	52.4	50.5	48.9	42.7	35.6	46.0	-4.15	-1.08	28.8	27.4	39.8
Group 4	52.0	53.3	52.6	43.6	39.7	48.2	-3.45	-1.33	29.0	25.2	35.3
M14	52.0	51.0	49.3	42.8	37.2	46.5	-3.77	-1.00	28.4	24.7	30.8
C103	47.4	46.0	40.2	38.2	28.5	40.1	-4.55	-0.92	31.2	43.2	52.5
M14xC103	52.0	52.7	49.3	42.1	36.2	46.5	-4.23	-1.20	30.3	29.4	37.4
Mean	52.4	53.1	49.9	43.2	37.3	47.2	-4.01	-1.20	29.4	29.2	37.4

<sup>a</sup>Mean for all population levels.

Table 7. Agronomic data for five groups of selections and three checks in testcross performance with two testers, data summarized for five population levels over five locations in 1965.

Composite	Yield, cwt per acre at population levels (x1000)					Mean	Regression coefficients		Percentage <sup>a</sup> grain moisture	Percentage barren stalks at population levels (x1000)	
	12	16	20	24	28		R <sub>I</sub>	R <sub>Q</sub>		24	28
Tester 1, WF9x I 205											
Group 0	56.6	60.2	56.2	44.8	43.7	52.3	-4.12	-1.20	27.9	30.4	33.1
Group 1	56.0	55.6	53.3	44.1	38.8	49.6	-4.60	-1.18	28.5	33.2	34.9
Group 2	56.0	57.3	53.9	47.6	41.3	51.2	-3.88	-1.31	29.4	23.4	36.7
Group 3	54.7	51.6	52.9	43.9	37.2	48.0	-4.28	-1.25	28.4	27.6	37.8
Group 4	52.5	52.7	53.5	43.5	38.3	48.1	-3.75	-1.53	28.7	24.9	36.1
M14	51.4	54.1	51.4	45.2	37.2	47.9	-3.72	-1.78	27.9	21.2	28.3
C103	46.1	45.8	39.5	37.6	25.9	39.0	-4.86	-1.31	31.3	44.3	55.5
M14xC103	53.4	51.8	47.7	40.2	32.7	45.2	-5.32	-1.11	29.4	31.4	40.3
Mean	53.3	53.6	51.1	43.4	36.9	47.7	-4.32	-1.33	28.9	29.6	37.8
Tester 2, Ia4810											
Group 0	54.2	60.6	55.3	51.2	42.2	52.7	-3.34	-2.10	28.5	21.0	31.9
Group 1	51.3	53.7	49.6	40.8	36.4	46.4	-4.26	-1.31	29.1	31.1	34.0
Group 2	52.0	54.9	50.0	44.2	39.4	48.1	-3.60	-1.15	30.1	28.0	36.5
Group 3	50.1	49.5	44.9	41.5	34.0	44.0	-4.02	-0.91	29.3	27.1	41.8
Group 4	51.6	53.9	51.7	43.6	41.0	48.4	-3.15	-1.13	29.3	25.5	34.5
M14	52.6	47.9	47.2	40.5	37.2	45.1	-3.82	-0.22	28.8	28.2	33.3
C103	48.7	46.2	40.9	38.9	31.1	41.2	-4.24	-0.53	32.1	42.0	49.5
M14xC103	50.7	53.6	50.8	44.0	39.8	47.8	-3.14	-1.29	31.2	27.4	34.6
Mean	51.4	52.5	48.8	43.1	37.6	46.7	-3.70	-1.08	29.8	28.8	37.0

<sup>a</sup>Mean for all population levels.

ier. For purposes of analysis, the three locations in 1964 and 1965 were considered as six random environments. Data and analyses of variance for individual experiments will not be presented, except as required to explain certain environmental effects.

The mean yields over all 64 entries at each population level for the six environments are summarized in table 9. The highest average yield in all environments was at 18,000 plants per acre; the yield at the 24,000 population level exceeded the yield at the 12,000 population level at only one environment, Hampton in 1964. Even the environment with the highest mean

yield, Ankeny in 1965, had a higher yield at rate 12,000 than at rate 24,000. Fertility may have been a limiting factor for yield at the highest rate at Ankeny in 1965, but the plants showed no evidence of nutrient deficiencies. It is more likely that water stress and early root lodging were the most important factors limiting yields in rate 24,000 at Ankeny in 1965.

A statistical comparison of population rates was not complete in the combined analysis because the replication within environments effect was not available. Differences among rates over all environments were highly significant. The environment x rates inter-



Table 8. Analysis of variance for grain yields of composite testcrosses and checks at five population densities, in five locations, 1965.

Source	D.F.	Mean squares
Locations (L)	4	37,754.11**
Replications in Locations	5	160.92
Rates (R)	4	7,333.08**
Linear (R <sub>l</sub> )	1	25,695.29**
Quadratic (R <sub>q</sub> )	1	3,262.91**
Remainder	2	187.06
Rates x Locations	4	611.44*
Error (b)	20	229.70
Testers (T)	1	182.12
Testers x Rates	4	61.15
Testers x Locations	4	53.97
Testers x Rates x Locations	16	41.20
Entries (E)	7	1,275.19**
0,1,2,3,4 vs. 5,6,7	1	3,858.89**
0 vs. 1,2,3,4	1	1,644.75**
1,2 vs. 3,4	1	282.74
1 vs. 2	1	142.30
3 vs. 4	1	247.31
5,6 vs. 7	1	686.30*
5 vs. 6	1	2,064.03**
Entries x Testers	7	174.70*
0,1,2,3,4 vs. 5,6,7 x T	1	324.16*
0 vs. 1,2,3,4 x T	1	165.95
1,2 vs. 3,4 x T	1	40.01
1 vs. 2 x T	1	0.12
3 vs. 4 x T	1	236.31
5,6 vs. 7 x T	1	143.57
5 vs. 6 x T	1	312.75*
Entries x Rates	28	34.74
Entries x Rates (linear)	7	30.09
0,1,2,3,4 vs. 5,6,7 x R <sub>l</sub>	1	28.86
0 vs. 1,2,3,4 x R <sub>l</sub>	1	7.52
1,2 vs. 3,4 x R <sub>l</sub>	1	17.40
1 vs. 2 x R <sub>l</sub>	1	46.17
3 vs. 4 x R <sub>l</sub>	1	49.49
5,6 vs. 7 x R <sub>l</sub>	1	0.52
5 vs. 6 x R <sub>l</sub>	1	60.68
Entries x Rates (quadratic)	7	14.38
Entries x Rates (remainder)	14	47.24
Entries x Locations	28	118.55**
0,1,2,3,4 vs. 5,6,7 x L	4	65.50
0 vs. 1,2,3,4 x L	4	50.20
1,2 vs. 3,4 x L	4	25.20
1 vs. 2 x L	4	13.51
3 vs. 4 x L	4	14.86
5,6 vs. 7 x L	4	38.10
5 vs. 6 x L	4	622.49**
Entries x Rates x Locations	112	41.66
E x R <sub>l</sub> x L	28	53.22
E x R <sub>q</sub> x L	28	28.36
E x R x L (remainder)	56	42.53
Entries x Testers x Rates	28	60.66
Entries x Testers x Locations	28	26.76
Entries x Testers x Rates x Locations	112	29.07
Error (c)	375	35.75

\* Significant at the 5% level.  
\*\* Significant at the 1% level.

Table 9. Estimated components of variance for lines and error, grain yields averaged for testcrosses of M14, C103, M14xC103 and 61 selections at three locations in 1964 and 1965.

Location		Population density (x1000)			Mean
		12	18	24	
1964					
Hampton	$\sigma^2_L$	11.10	49.36	25.39	
	$\sigma^2$	17.86	21.66	41.52	
Ames	Yield, cwt/acre	60.60	65.80	61.10	62.50
	$\sigma^2$	8.48	23.95	24.60	
Ankeny	Yield, cwt/acre	62.20	20.87	28.95	62.80
	$\sigma^2$	14.56	66.10	60.10	
1965					
	$\sigma^2_L$	5.60	11.56	34.64	
Hampton	$\sigma^2$	32.86	37.54	38.58	
	Yield, cwt/acre	54.50	55.50	47.40	52.40
Ames	$\sigma^2_L$	17.76	20.25	32.76	
	$\sigma^2$	18.82	26.01	24.44	
Ankeny	Yield, cwt/acre	58.40	61.20	58.40	59.30
	$\sigma^2$	15.60	35.00	57.30	
1964					
	$\sigma^2_L$	22.27	25.53	36.81	
Ames	$\sigma^2$	58.80	60.00	47.00	55.20
	Yield, cwt/acre	9.04	30.21	26.52	
Ankeny	$\sigma^2_L$	18.26	29.55	82.82	
	$\sigma^2$	68.00	73.40	63.20	68.20
Mean	Yield, cwt/acre	60.40	63.70	56.20	

action could not be tested, but the data in table 9 suggest that this interaction would be significant.

Estimated components of variance for lines and error for the rates of evaluation at each of the environments are presented in table 9. The component of variance for lines was much smaller at the 12,000 population level than either the 18,000 or 24,000 population level in all environments. Also, the error variance was reduced at rate 12,000, but not enough to compensate for the reduced variance among lines. The error variance increased with population levels, and in two instances, Hampton in 1964 and Ankeny in 1965, the increase was considerable from rate 18,000 to rate 24,000. Comparing rates 18,000 and 24,000, the estimated variance component for lines was less in rate 24,000 in two cases and greater in three cases. Heritability values would be highest at rate 18,000 in three environments and at rate 24,000 in the remaining three environments.

Agronomic data for WF9xI205 testcrosses of the 61 selections, M14, C103 and M14xC103, summarized over six environments, are presented in table 10. The combined analysis of variance for grain yields, and appropriate orthogonal comparisons in entries and interactions with rates and environments, are shown in table 11.

Yield differences among entries (64 testcrosses) were highly significant, and all except four of the mean squares for orthogonal comparisons were significant, or highly significant. Mean testcross yield performance of the selections was greater than for the checks (p 0.01), and group 0 mean was greater than the mean of the other four groups (p<0.05). Groups 1 and 2, selected on the basis of testcross performance with WF9xI205, yielded significantly more than groups 3 and 4, selected on the basis of inbred pheno-



Table 10. Agronomic performance in testcrosses of 61 individual selections and three checks at three population densities, combined over three locations and two years.

Selection number	Yield, cwt per acre at population density (x1000)				Regression coefficients		Percentage <sup>a</sup> grain moisture	Percentage <sup>a</sup> lodging		Percentage <sup>b</sup> barren stalks
	12	18	24	Mean	R <sub>l</sub>	R <sub>q</sub>		Root	Stalk	
01	62.4	67.6	62.2	64.0	-0.10	-1.77	23.9	14.6	9.7	12.7
02	60.0	66.9	61.0	62.6	+0.50	-2.13	22.4	16.4	13.9	4.7
03	62.9	65.3	60.7	63.0	-1.10	-1.17	25.4	13.0	8.3	5.5
Group 0 Mean	61.8	66.6	61.3	63.2	-0.25	-1.68	23.9	14.7	10.6	7.6
04	62.0	64.5	57.8	61.4	-2.10	-1.53	27.3	9.6	21.0	5.4
05	62.5	65.1	58.0	61.9	-2.25	-1.62	24.7	4.9	15.9	8.5
06	62.8	65.0	56.3	61.4	-3.25	-1.82	23.2	10.8	10.1	9.4
07	59.9	64.9	59.6	61.5	-0.15	-1.72	22.3	8.5	12.1	6.1
08	58.9	59.5	47.2	55.2	-5.85	-2.15	25.6	3.8	7.2	18.5
09	57.8	64.0	48.6	56.8	-4.60	-3.60	23.6	8.2	7.6	12.9
10	60.9	66.0	61.4	62.8	+0.25	-1.62	26.4	13.2	10.7	6.0
11	61.5	68.2	59.3	63.0	-1.10	-2.60	23.9	6.7	16.2	3.7
12	59.3	63.2	56.9	59.8	-1.20	-1.70	26.0	7.9	17.7	10.1
13	60.8	65.4	55.2	60.4	-2.80	-2.47	24.4	20.4	13.3	8.2
14	63.3	63.9	54.1	60.4	-4.60	-1.73	24.5	10.7	10.6	7.0
15	65.4	69.8	60.6	65.3	-2.40	-2.27	24.6	9.4	11.5	4.5
16	62.5	62.7	53.8	59.7	-4.35	-1.52	23.4	6.2	5.6	11.8
Group 1 Mean	61.4	64.8	56.1	60.7	-2.65	-2.02	24.6	9.3	12.3	8.6
17	57.9	61.6	51.9	57.1	-3.00	-2.23	25.1	11.2	8.9	11.4
18	64.0	68.1	64.2	65.4	+0.10	-1.33	25.3	6.4	17.3	4.8
19	63.7	65.1	58.6	62.5	-2.55	-1.32	23.8	8.5	13.6	6.3
20	56.7	56.0	55.6	56.1	-0.55	+0.05	25.2	11.0	6.9	6.7
21	58.8	63.8	58.6	60.4	-0.10	-1.70	25.0	3.5	11.4	8.3
22	57.1	65.2	57.2	59.8	+0.05	-2.68	23.9	17.8	16.7	5.7
23	64.6	70.5	57.6	64.2	-3.50	-3.13	23.4	16.8	10.3	7.6
24	63.9	66.7	59.8	63.5	-2.05	-1.62	28.4	18.4	8.7	7.7
25	61.5	64.4	56.4	60.8	-2.55	-1.82	24.5	8.6	9.0	8.6
26	59.7	62.5	50.5	57.5	-4.60	-2.47	25.8	11.4	17.7	8.6
27	60.8	63.7	57.2	60.6	-1.80	-1.57	25.4	12.9	21.3	10.9
28	60.1	64.2	53.9	59.4	-3.10	-2.40	25.5	18.2	6.1	11.3
29	59.8	66.7	59.9	62.1	+0.05	-2.28	22.8	11.5	10.9	11.0
Group 2 Mean	60.7	64.5	57.0	60.7	-1.85	-1.89	24.9	12.0	12.2	8.4
30	61.2	69.4	59.4	63.3	-0.90	-3.03	25.5	8.7	20.0	10.2
31	58.4	63.6	57.5	59.8	-0.45	-1.88	21.6	7.6	15.7	6.2
32	53.8	53.9	45.1	50.9	-4.35	-1.48	21.8	2.6	17.7	14.3
33	57.9	62.3	56.6	58.9	-0.65	-1.68	23.9	14.2	22.2	7.2
34	58.3	55.3	50.3	54.6	-4.00	-0.33	24.6	8.0	11.2	15.9
35	55.0	47.7	35.8	46.1	-9.60	-0.77	24.8	2.5	8.0	22.7
36	57.8	62.4	58.2	59.4	+0.20	-1.47	24.3	6.1	8.8	6.4
37	54.2	55.0	54.1	54.5	-0.05	-0.28	22.2	5.7	4.7	9.1
38	61.2	62.4	55.2	59.6	-3.00	-1.40	26.9	9.5	13.8	9.5
39	60.4	61.5	57.1	59.7	-1.65	-0.92	22.6	3.9	8.1	7.5
40	65.7	67.0	59.0	63.9	-3.35	-1.55	27.5	19.5	30.2	7.5
41	55.8	56.5	46.7	53.0	-4.55	-1.75	25.3	9.4	5.7	15.8
42	61.1	60.6	52.4	58.0	-4.35	-1.28	24.1	7.2	15.5	12.5
43	62.8	73.9	66.0	67.6	+1.60	-3.17	23.6	11.4	15.7	3.9
44	65.4	69.2	61.4	65.3	-2.00	-1.93	23.3	17.2	11.0	6.8
45	62.7	68.2	59.8	63.5	-1.45	-2.32	24.2	10.5	8.8	6.6
Group 3 Mean	59.5	61.8	54.7	58.6	-2.40	-1.57	24.1	9.0	13.6	10.1
46	59.0	62.8	54.1	58.7	-2.45	-2.08	21.8	12.1	23.4	10.3
47	54.7	56.9	46.8	52.8	-3.95	-2.05	23.2	8.0	16.7	16.4
48	59.5	61.7	56.5	59.2	-1.50	-1.23	20.9	6.2	16.3	7.4
49	63.8	69.3	61.7	64.9	-1.05	-2.18	24.5	5.3	21.3	7.5
50	63.4	62.9	54.7	60.3	-4.35	-1.28	27.3	15.6	16.6	11.3
51	56.9	61.7	49.1	55.9	-3.90	-2.90	25.2	5.3	18.0	12.1
52	60.1	64.0	52.5	58.9	-3.80	-2.57	22.6	8.3	15.4	10.5
53	61.9	63.7	57.3	61.0	-2.30	-1.37	25.0	10.9	10.2	6.8



Table 10. (Continued)

Selection number	Yield, cwt per acre at population density (x1000)				Regression coefficients		Percentage <sup>a</sup> grain moisture	Percentage <sup>a</sup> lodging		Percentage <sup>b</sup> barren stalks
	12	18	24	Mean	R <sub>1</sub>	R <sub>q</sub>		Root	Stalk	
54	56.6	61.0	59.9	59.1	+1.65	-0.92	21.1	10.8	16.0	4.0
55	57.8	62.7	56.6	59.0	-0.60	-1.83	23.3	6.6	5.8	5.5
56	61.8	65.8	57.6	61.8	-2.10	-2.03	26.8	8.3	13.4	6.8
57	61.6	62.4	57.9	60.6	-1.85	-0.88	24.3	5.4	15.8	5.1
58	64.4	71.7	69.9	68.6	+2.75	-1.52	25.1	9.1	15.6	3.2
59	62.1	70.4	60.6	64.4	-0.75	-3.02	25.3	9.7	21.2	3.8
60	66.0	70.2	57.8	64.6	-4.10	-2.77	24.1	3.2	9.7	9.9
61	63.2	61.7	56.4	60.4	-3.40	-0.63	22.6	6.9	5.1	11.8
Group 4 Mean	60.8	64.3	56.8	60.6	-2.00	-1.83	23.9	8.2	15.0	8.3
All Selections										
Mean	60.6	63.9	56.4	60.3	-2.10	-1.80	24.3	9.8	13.2	8.8
M14	56.1	55.6	56.1	55.9	0.00	+0.17	23.4	19.3	8.8	4.5
C103	55.0	58.1	50.2	54.4	-2.40	-1.83	25.9	4.5	8.3	14.6
M14xC103	59.7	62.2	52.2	58.0	-3.75	-2.08	24.2	8.4	14.3	7.8
Checks Mean	56.9	58.6	52.8	56.1	-2.05	-1.25	24.5	10.7	10.5	9.0
Grand Mean	60.4	63.7	56.2	60.1	-2.10	-1.80	24.4	9.8	11.6	8.8

<sup>a</sup>Data for 18,000 plants per acre.<sup>b</sup>Data for 24,000 plants per acre.

typic appearance. Groups 1, 2 and 4 had equal mean yields over all environments and population levels; group 3, which was selected at a low stand level, yielded significantly less than group 4.

In nonorthogonal comparisons of each group with the testcross of M14xC103, only the comparisons for groups 0 and 1 were significant. Groups 2 and 4 had yields similar to the yield of group 1, but were not significantly different from M14xC103 because of greater interactions with environments. Chance deviations can be an important factor in these comparisons where the degrees of freedom are so small, and caution must be used in interpreting the results.

Testcrosses of selections in group 0 were all uniformly high yielding as an average over all rates and environments (table 10), with no significant variation among them. Highly significant differences were evident among the selections within groups 1, 2, 3 and 4; less in groups 1 and 2 than in groups 3 and 4 (table 11). Lower variances were expected in groups 1 and 2 because they were selected through three generations for high yield in crosses with WF9xI205. Group 3 had the highest variance because it had several low- and high-yielding genotypes. Group 4 had only one low-yielding genotype, and selection 58, highest of all entries. Selection 58 was selected on the basis of phenotypic appearance in high-stand level nurseries. Evidently, the phenotypic selection under high-stand levels, as for group 4, has been more effective in eliminating genotypes with low combining ability than was the case where stand levels were low, as for group 3. If an L.S.D. of 3.86 for  $P=0.05$  and based on the genotype x environment interaction is used for making comparisons, the number of selection testcrosses that exceeded the testcross of M14xC103 in each group was: group 0, three; group 1, four; group 2, five; group 3, five; and group 4, four. Since

the three selections of group 0 actually belong to groups 1 and 2, there were more superior testcrosses in groups 1 and 2 than in groups 3 and 4. This was expected if selection for nonadditive gene action, or specific combining ability, had been effective.

The entries x environments interaction was highly significant, and all except three of the orthogonal comparisons were significant or highly significant. Testcrosses of selections in group 0 did not have a significant genotypes x environments interaction, whereas for groups 1, 2, 3 and 4, highly significant interactions were obtained. This result could be a sampling phenomenon because there are only three selections in group 0, but it may also mean that more extensive testing has resulted in genotypes more stable in their performance under varying environmental conditions. Selections in group 0 survived testing at high and low stand levels, but selections in groups 1 and 2 were selected on the basis of performance at only one stand level.

The linear trend for group 0 was different from the average of the other four groups ( $p<0.05$ ). Group 0 had similar yields at rates 12,000 and 24,000, whereas the decrease of yield from rate 12,000 to rate 24,000 was 4.4 cwt as an average for groups 1, 2, 3 and 4. Differences among yield trends for groups 1, 2, 3 and 4 were not statistically significant, but the groups developed at the higher plant populations had relatively better yields in denser stands. All groups of selections suffered less than the testcross of M14xC103 in the dense stands.

The individual testcrosses in all groups, except 0, had varied yield trends over population rates. Linear regression coefficients in group 2 ranged from +0.10 to -4.60, although the variation was not significant. Group 3 testcrosses had the greatest range, +1.60 for selection 43 to -9.60 for selection 35. These were the



Table 11. Analysis of variance for grain yields of testcrosses of 61 selections and three checks for data combined over six environments, 1964 and 1965.

Source	D.F.	Mean squares
Rates (R)	2	10,766.49**
Linear (R <sub>l</sub> )	1	6,859.71*
Quadratic (R <sub>q</sub> )	1	14,673.27**
Environments x Rates	10	862.74
Entries (E)	63	573.42**
0,1,2,3,4 vs. 5,6,7	1	1,771.86**
0 vs. 1,2,3,4	1	976.88*
1,2 vs. 3,4	1	611.60**
1 vs. 2	1	0.00
3 vs. 4	1	1,145.21*
Among 0	2	10.05
Among 1	12	242.57**
Among 2	12	281.86**
Among 3	15	1,160.93**
Among 4	15	509.03**
5,6 vs. 7	1	196.46
5 vs. 6	1	40.50
Entries x Rates	126	71.27**
Entries x Rates (linear)	63	102.03**
0,1,2,3,4 vs. 5,6,7 x R <sub>l</sub>	1	0.33
0 vs. 1,2,3,4 x R <sub>l</sub>	1	269.30*
1,2 vs. 3,4 x R <sub>l</sub>	1	0.47
1 vs. 2 x R <sub>l</sub>	1	109.84
3 vs. 4 x R <sub>l</sub>	1	35.54
Among 0 x R <sub>l</sub>	2	16.28
Among 1 x R <sub>l</sub>	12	82.08*
Among 2 x R <sub>l</sub>	12	60.19
Among 3 x R <sub>l</sub>	15	171.51**
Among 4 x R <sub>l</sub>	15	102.20**
5,6 vs. 7 x R <sub>l</sub>	1	100.83
5 vs. 6 x R <sub>l</sub>	1	66.74
Entries x Rates (quadratic)	63	40.51
Entries x		
Environments (En)	315	69.33**
0,1,2,3,4 vs. 5,6,7 x En	5	46.38
0 vs. 1,2,3,4 x En	5	134.70**
1,2 vs. 3,4 x En	5	21.23
1 vs. 2 x En	5	147.02**
3 vs. 4 x En	5	89.24*
Among 0 x En	10	43.93
Among 1 x En	60	61.18**
Among 2 x En	60	76.39**
Among 3 x En	75	73.12**
Among 4 x En	75	55.69**
5,6 vs. 7 x En	5	109.67**
5 vs. 6 x En	5	148.55**
Entries x Rates		
x Environments	630	38.71**
E x R <sub>l</sub> x En	315	46.90**
E x R <sub>q</sub> x En	315	30.52
Pooled error	882	29.79

\*Significant at the 5% level.

\*\*Significant at the 1% level.

highest and lowest yielding testcrosses, respectively, in group 3. Testcrosses in group 4 had linear regression coefficients ranging from +2.75 for selection 58, the highest yielding line, to -4.35 for selection 50. Generally, the highest yielding lines had linear regression values that were positive, or near zero if negative. As a contrast, testcrosses with the greatest negative linear regression values had the lowest mean yields.

The entries x rates quadratic interaction was not significant, and none of the orthogonal comparisons was significant. All testcrosses except number 20 had mean yields at the 18,000 population level greater

than the average for the 12,000 and 24,000 population levels. All except five of the 61 testcrosses had a higher yield at rate 18,000 than at either rate 12,000 or rate 24,000.

Some general comparisons can be made for yield performance between the composite and individual cross tests. Group 0 was the highest yielding group in both series of experiments. Considering only the WF9xI205 composites, groups 1, 2 and 4 had similar yields, and group 3 was the lowest yielding group in both cases. Selections were superior to M14xC103 in the two sets. The testcross of C103 yielded better relative to M14 in the individual cross experiments than in the composite experiments. Yield patterns of the groups across population levels were similar in both sets of environments. Group comparisons were less consistent over environments in the individual cross experiments than in the composite experiments. This may be a reflection of greater stability of yield performance where testcrosses are evaluated as composites than where evaluated as individual entries.

Data obtained for other agronomic characters were not analyzed statistically. Differences among the groups for grain moisture were small, and all groups exceeded M14. Considerable variation existed among the individual testcrosses, some being as early as the testcross of M14 and a few others being later than the testcross of C103. Some of the highest yielding testcrosses, for example 58, 43, 18, 15 and 44, did not have as much grain moisture as the testcross of C103.

Differences among the groups for root and stalk lodging were relatively small and did not differ greatly from (WF9xI205)(M14xC103). Variation among the testcrosses was large, but only a few crosses were equal to (WF9xI205)x(C103). There appears no relationship between the breeding method to develop the lines and the lodging resistance; rather, the selections appear random samples for root and stalk strength. However, some of the higher yielding testcrosses were nearly equal to the C103 testcross for lodging resistance.

The groups did not have large differences for percentage of barren stalks. In both tests, group 3 had the greatest amount of barrenness. There were large differences among individual crosses, ranging from 3.2 percent for selection 58 to 22.7 percent for selection 35. Testcrosses that had a positive linear regression coefficient had few barren stalks. Most of the testcrosses were less barren than the C103 testcross, but only a few testcrosses were less barren than the M14 testcross.

#### Tests of Inbred Lines

The replicated test of inbred lines grown in 1963 contained only the visually selected lines and M14 and C103. Since this was a preliminary experiment, agronomic data of the individual entries will not be presented, but the analysis of variance for grain yields is given in table 12.

There was some drought stress in late June and early July, but sufficient moisture became available before the plants entered the critical stage of development before and during silk emergence. Grain yields at 12,000 and 24,000 plants per acre, were 32.1 and 43.9 cwt per acre, respectively, and the difference was highly significant.



Table 12. Analysis of variance for inbred grain yield of 36 selections, M14 and C103 in 1963.

Source	D.F.	Mean squares
Replications	4	207.65
Rates (R)	1	13,248.81**
Rates x Replications	4	38.02
Entries	37	467.52**
Group 3 vs. group 4	1	572.54**
3 + 4 vs. checks	1	1,347.70**
Among group 3	17	186.62**
Among group 4	17	569.13**
M14 vs. C103	1	2,530.35**
Entries x Rates	37	81.07**
3 vs. 4 x R	1	480.23**
3 + 4 vs. checks x R	1	193.45**
Among 3 x R	17	52.31**
Among 4 x R	17	81.99**
M14 vs. C103 x R	1	42.52
Error b	296	20.53
Total	379	

\*Significant at the 5% level.

\*\*Significant at the 1% level.

The variance for inbred grain yield was highly significant. The comparison of selections versus checks was highly significant, but only because of a low yield for inbred C103. Group 4 yielded more than group 3 and both groups yielded less than M14. One selection in group 4 yielded 60.2 cwt per acre at rate 24,000, an outstanding production for a highly inbred strain of corn.

The selections yielded 38.2 percent more at rate 24,000 than at rate 12,000, whereas the checks had an increase of only 22.2 percent ( $p < 0.01$ ). The yield increase from rate 12,000 to rate 24,000 was greater for group 4 than group 3 ( $p < 0.01$ ). All inbred lines yielded more at rate 24,000 than at rate 12,000, but the increase varied among the lines.

Other agronomic data obtained were not analyzed statistically; however, some comparisons of mean values are useful. Several of the lines were as early or earlier than M14 in date of silking, and none was as late as C103. The delay in silk emergence after pollen shedding was similar to M14 (0.3 days) in many selections and none of the selections was delayed as long as C103 (4.7 days). With the exception of five selections, the amount of barrenness was negligible; inbreds M14 and C103 at rate 24,000 had 1.4 and 26.2 percent barren plants, respectively. There was no association between the delay in silk emergence and amount of barrenness in this experiment because there was pollen available in the field even though the pollen of a particular selection was gone before all silks had emerged.

All inbred selections that were included in combining ability studies were evaluated as inbred lines in replicated experiments in 1964 and 1965. Environmental conditions were favorable for plant growth and grain development in 1964. Drouth conditions in July and August of 1965 restricted plant growth and grain development; wilting was evident in some lines on several days during the critical stage before and during silk emergence. Means for the agronomic characters studied are presented in table 13, and the

combined analysis of variance for grain yields in the two years is in table 14.

The grain yield over all entries for the two years was 22.1 cwt per acre for 12,000 plants per acre and 28.2 cwt per acre for 24,000 plants per acre. The difference is not significant if the rate x year interaction is used to calculate the F value, because there is only one degree of freedom in each of the numerator and denominator. Mean yields at rates 12,000 and 24,000 in 1964 were 24.4 and 32.5 cwt per acre, respectively, and in 1965, 20.1 and 23.1 cwt per acre, respectively. The grain yields were higher at rate 24,000 than at rate 12,000 in 1965 in spite of the unfavorable environmental conditions for plant growth and grain development.

The difference in mean yield of the selections (25.4 cwt) and the checks (18.1 cwt) was highly significant (table 14), but the selections mean yield was similar to M14 (25.8 cwt). All group mean yields were greater than the means of the checks, but only groups 0 and 4 were greater than M14. Group 0 lines yielded 28.5 cwt while the mean for groups 1, 2, 3 and 4 was 25.2 cwt; the difference was highly significant. The visually selected lines, groups 3 and 4, yielded 3.8 cwt more than groups 1 and 2, not including group 0 ( $p < 0.01$ ). Groups 1 and 2 were not different in mean yield, but the difference between groups 3 and 4 was significant, group 4 being 2.7 cwt higher.

There was a wide range of grain yields among the inbred selections in each group (table 13). The lowest individual yields were in groups 1 and 2, and the highest individual yields were in group 4. Groups 1 and 2 were expected to have some low-yielding lines because inbred yield was not emphasized in the selection of these lines, but it was surprising to find some low-yielding selections in group 3 where seed yield was a criterion of selection. The highest-yielding selection was 58 in group 4. It was also the highest-yielding selection in the smaller test of inbreds in 1963, and the testcross of this line had the highest mean yield over all rates and environments. There were inbred lines in each group that yielded better than M14, indicating success in the selection of genotypes that combined favorable genes from both M14 and C103.

Variation among the entries in yield response to different stand densities was highly significant. Inbred M14 had a yield increase of 6.0 cwt from rate 12,000 to rate 24,000, the selections had an increase of 6.7 cwt, but inbred C103 showed a decrease of 2.2 cwt. Groups 1 and 2 had a smaller yield difference than did groups 3 and 4 between the 12,000 and 24,000 population levels. If the selections in group 0 are included in groups 1 and 2, the yield responses from 12,000 to 24,000 plants per acre were more nearly equal for the two sets of lines. Comparing the selections of groups 3 and 4, the lines of group 4 had a greater yield advantage at 24,000. Data for mean yields at rate 12,000 and at rate 24,000 in table 13 show that most lines yielded more at rate 24,000 than at rate 12,000, although the amount of the advantage varied greatly. Selections 12, 17, 26, 32, 34, 38, 40 and 41 yielded less at rate 24,000 than at rate 12,000. Five of these selections are in group 3, and none is



Table 13. Agronomic data for 61 selections, M14 and C103 compared at two population densities in 1963 and 1964.

Selection number	Yield cwt/acre at stand (x1000)		Mean	Days after July 1 <sup>a</sup>		Differ- ence	*Percentage lodged <sup>a</sup>		Percentage barren stalks at stand (x1000)		Plant height <sup>a</sup> cm
	12	24		Pollen shed	Silks emerged		Root	Stalk	12	24	
01	20.8	31.3	26.1	30.1	32.4	2.3	23.1	8.4	2.1	8.0	129.3
02	24.7	27.5	26.1	29.4	30.2	0.8	3.8	10.6	0.0	12.6	144.3
03	29.6	37.1	33.4	32.1	32.5	0.4	10.4	17.4	2.0	10.1	139.2
Group 0 Mean	25.0	32.0	28.5	30.5	31.7	1.2	12.4	12.1	1.4	10.2	137.6
04	24.8	33.4	29.1	31.2	34.2	3.0	15.7	18.3	12.3	5.7	142.3
05	20.7	23.1	21.9	32.9	35.1	2.2	1.1	14.5	4.6	23.4	141.0
06	15.8	20.3	18.1	28.2	33.0	4.8	5.6	2.7	0.0	10.1	158.0
07	22.3	32.4	27.4	29.6	32.5	2.9	10.5	4.3	6.5	6.5	150.1
08	16.2	17.1	16.7	33.7	36.1	2.4	9.1	4.3	7.9	34.3	130.9
09	16.9	20.2	18.6	31.4	32.9	1.5	5.7	15.0	6.1	25.3	124.4
10	25.8	32.9	29.4	32.3	33.2	0.9	12.2	17.7	0.7	8.8	147.5
11	22.2	32.3	27.3	31.8	33.5	1.7	5.3	16.4	2.7	8.3	150.2
12	14.5	11.6	13.1	29.6	35.7	6.1	0.4	7.3	8.4	40.4	120.5
13	19.0	25.1	22.1	29.2	32.3	3.1	14.8	17.5	3.2	17.3	138.6
14	26.0	26.9	26.5	29.6	31.8	2.2	0.9	40.3	1.3	12.8	124.5
15	27.7	40.1	33.9	32.9	32.5	-0.4	5.1	5.9	5.7	3.5	136.6
16	19.6	20.5	20.1	31.9	35.8	3.9	0.3	3.4	1.3	13.3	140.9
Group 1 Mean	20.9	25.8	23.4	31.1	33.7	2.6	6.7	12.9	4.7	16.1	138.9
17	16.5	14.8	15.7	33.3	36.9	3.6	3.5	1.3	9.8	29.6	131.5
18	25.3	37.8	31.6	31.4	31.4	0.0	19.5	10.7	0.0	1.4	139.6
19	24.6	28.8	26.7	32.3	35.0	2.7	3.8	14.0	0.0	10.6	122.4
20	22.7	30.6	26.7	30.1	32.0	1.9	27.7	5.7	14.8	10.0	145.5
21	12.8	15.3	14.1	30.7	34.0	3.3	0.2	4.4	19.4	26.8	125.4
22	23.9	35.3	29.6	29.1	30.0	0.9	8.6	3.1	1.9	8.7	125.0
23	23.8	28.9	26.4	32.0	32.9	0.9	31.8	8.3	1.4	7.5	140.7
24	25.7	32.1	28.9	34.7	36.5	1.8	11.6	0.7	0.0	6.4	132.1
25	27.5	36.1	31.8	30.4	31.7	1.3	4.3	18.1	4.4	15.9	156.8
26	15.3	12.4	13.9	34.9	37.3	2.4	2.9	13.1	10.3	44.3	134.6
27	20.8	31.0	25.9	29.8	32.1	2.3	12.6	6.9	8.4	23.3	140.1
28	5.7	12.5	9.1	31.9	36.8	4.9	12.7	1.2	28.3	32.3	152.2
29	18.9	19.7	19.3	34.0	36.1	2.1	1.0	3.7	7.6	36.0	139.7
Group 2 Mean	20.3	25.8	23.1	32.0	33.7	1.7	10.8	7.0	8.2	19.4	137.3
30	19.1	24.7	21.9	30.9	32.6	1.7	4.5	14.7	3.3	10.9	136.1
31	18.1	25.5	21.8	30.9	32.1	1.2	0.7	15.6	14.1	17.5	114.0
32	23.7	22.9	23.3	31.7	32.0	0.3	0.6	21.2	5.2	19.0	120.5
33	20.4	26.5	23.5	29.0	30.7	1.7	3.2	24.5	4.8	15.9	117.4
34	16.9	16.4	16.7	29.4	31.9	2.5	1.2	19.2	4.7	23.2	100.6
35	25.9	34.6	30.3	31.1	34.7	3.6	1.1	6.1	11.1	6.5	136.7
36	23.2	34.6	28.9	30.9	31.9	1.0	1.3	13.1	-4.5	4.9	146.3
37	22.2	30.7	26.5	27.9	31.9	4.0	0.7	1.3	3.9	7.9	128.8
38	23.3	17.8	20.6	32.9	36.0	3.1	8.2	6.0	6.0	29.6	140.1
39	25.0	31.2	28.1	34.1	35.2	1.1	0.1	7.2	1.4	8.2	128.2
40	21.7	20.2	21.0	36.9	37.7	0.8	29.6	29.7	3.3	15.1	136.3
41	22.3	21.7	22.0	33.5	35.8	2.3	25.2	7.1	5.9	20.3	133.8
42	27.4	32.9	30.2	33.7	36.1	2.4	1.6	31.8	0.7	14.7	136.2
43	26.1	36.1	31.1	29.9	33.2	3.3	16.3	26.9	0.7	5.0	142.2
44	27.1	37.7	32.4	30.2	31.7	1.5	7.3	5.6	3.3	9.4	127.9
45	26.9	38.7	32.8	30.0	31.8	1.8	4.3	4.0	0.7	6.5	129.0
Group 3 Mean	22.5	28.3	25.7	31.4	33.5	2.1	6.6	14.6	4.6	13.4	129.6
46	24.4	32.2	28.3	29.1	31.5	2.4	9.7	26.9	10.8	8.3	146.8
47	16.0	21.9	19.0	31.5	32.6	1.1	12.5	6.5	3.3	16.2	119.9
48	27.9	41.8	34.9	30.2	30.8	0.6	1.7	6.2	0.0	6.3	121.0
49	17.8	18.4	18.1	34.3	37.2	2.9	0.9	10.2	11.7	28.8	141.5
50	27.8	36.9	32.4	34.8	36.0	1.2	18.4	23.1	0.0	4.5	136.2
51	17.7	20.0	18.9	36.1	38.2	2.1	1.7	6.4	17.1	23.8	144.4
52	23.8	33.4	28.6	27.4	29.1	1.7	5.9	14.7	11.6	6.8	140.1
53	20.9	26.1	23.5	30.3	33.8	3.5	5.5	12.0	5.1	8.1	146.7
54	27.9	39.5	33.7	29.0	30.2	1.2	9.9	10.6	2.8	4.2	126.4
55	22.9	32.4	27.7	27.7	30.3	2.6	1.2	1.6	1.9	3.8	126.3



Table 13. (Continued)

Selection number	Yield cwt/acre at stand (x1000)		Mean	Days after July 1 <sup>a</sup>		Differ- ence	Percentage lodged <sup>a</sup>		Percentage barren stalks at stand (x1000)		Plant height <sup>a</sup> cm
	12	24		Pollen shed	Silks emerged		Root	Stalk	12	24	
56	19.4	26.1	22.8	28.5	31.6	3.1	2.2	4.7	3.2	12.7	127.5
57	26.3	32.4	29.4	30.9	31.7	0.8	11.6	9.1	0.0	5.2	147.8
58	31.1	47.7	39.4	32.3	32.5	0.2	21.3	18.2	0.0	4.6	169.2
59	26.8	33.4	30.1	32.1	32.6	0.5	13.6	19.9	5.2	9.2	140.0
60	30.1	35.8	33.0	30.2	31.6	1.4	7.0	12.6	0.0	3.9	145.5
61	27.6	40.0	33.8	27.9	30.5	2.6	11.9	3.3	14.2	8.3	148.5
Group 4 Mean	24.3	32.4	28.4	30.8	32.5	1.7	8.4	11.6	5.4	9.7	139.2
All selections Mean	22.3	28.5	25.4	31.2	33.2	2.0	8.3	11.8	5.4	14.1	131.1
M14	22.8	28.8	25.8	30.9	32.0	1.1	14.6	12.2	2.6	12.3	121.6
C103	11.4	9.2	10.3	33.0	39.1	6.1	2.4	0.6	39.2	64.6	148.9
Checks Mean	17.1	19.0	18.1	32.0	35.6	3.6	8.5	6.4	20.9	38.5	135.3
Experiment Mean	22.1	28.2	25.2	31.2	33.3	2.1	8.3	11.6	5.9	14.9	136.1

<sup>a</sup> Data averaged for 12,000 and 24,000 stand levels.

in group 4. Selection 35, which had low testcross performance, had relatively high inbred yields and was 8.7 cwt better at rate 24,000 than at rate 12,000.

The difference between groups 1 and 2 vs. groups 3 and 4 was significantly greater in 1964 than in 1965 ( $p < 0.01$ ). By contrast, the difference between groups 3 and 4 was greater in 1965 than in 1964. The relative performances among lines within each of the five groups were significantly different ( $p < 0.01$ ) in the two years.

The 24,000 population level in the inbred experiments caused a delay in dates of pollen shedding and silk emergence in each of the five groups and the checks. In all except group 3, the delay was greater for silk emergence. Differences among the groups for dates of pollen shedding and silk emergence were small; group 0, the earliest, was slightly earlier than M14. The data of most interest pertain to the delay in silk emergence after pollen shedding. The delay for M14 was only 1.1 days, but for C103, it was 6.1 days (table 13). Groups 2 and 4, developed under high stand levels, had a smaller delay of silk emergence than groups 1 and 3, developed under low stand levels. Two of the three lines in group 0 had only a short delay in silk emergence. The selection criterion of simultaneous silk emergence and pollen shedding in groups 3 and 4 was more successful in group 4. This was expected because the selection pressure was greater in group 4. There are lines in all groups that were similar to M14 for simultaneous silk emergence and pollen shedding, but group 1 has five lines that had more than 3 days delay, and one line had a delay equal to C103. Some lines were as late as C103 in pollen shedding, but none silked as late.

The incidence of barren stalks was partially caused by the delay in silk emergence. Group differences were not large, but it is evident that groups 0, 3 and 4 had less barrenness than groups 1 and 2. If the lines in group 0 are included in groups 1 and 2, then group

4 had the lowest percentage of barren stalks. This result is a reflection of the strong selection pressure for simultaneous silk emergence and pollen shedding during the development of the lines in group 4. None of the selections was as barren as C103, and many were less barren than M14. If barrenness is mainly an expression of a delay in silk emergence, then the observed barrenness was less than would be observed if each plot were isolated. In plantings of pure stands, some selections, such as 6, 12, 28 and 37, would have more barren stalks and, thus, lower yields than obtained in these tests.

Plant height was similar among the groups except for group 3, which was considerably shorter (table 13). Plant height per se was not a selection criterion in groups 1 and 2. If selection for silk emergence under high-stand density resulted in increased plant height as an associated response, then there would be selection for taller genotypes in group 4. The data for delay of silk emergence, barren stalks and plant height in table 13 show several inbreds, including M14 and C103, that refute the positive correlation. Selection 58, which was the highest yielding inbred, had the greatest plant height.

We had expected that the inbred selections developed at high-stand densities would have better resistance to root and stalk lodging than selections developed at low-stand levels. The data in table 13, do not support this expectation. Group differences in root and stalk lodging probably were not great enough to be significant. There was a wide range among the selections for percentage of plants with root lodging or broken stalks; several lines appeared equal to C103, which contributes good strength to hybrid combinations.

The inbred tests of 1964 and 1965 were split-plot designs with population levels or rates being the main plots. Some comparisons among groups 1, 2, 3 and 4 (group 0 selections were included in groups 1 and 2) were made by analyzing the yield by groups for



Table 14. Analysis of variance for grain yields of 61 selections, M14 and C103 for data combined over two years.

Source	D.F.	Mean squares
Years (Y)	1	13,759.70
Replications in years	8	130.80
Rates (R)	1	11,084.64
Rates x Years	1	1,522.41*
Error (b)	8	184.18
Entries	62	850.70**
0, 1, 2, 3, 4 vs. 5, 6	1	2,136.63**
0 vs. 1, 2, 3, 4	1	582.87**
1, 2 vs. 3, 4	1	4,149.08**
1 vs. 2	1	14.39
3 vs. 4	1	1,134.23**
Among 0	2	89.42
Among 1	12	730.61**
Among 2	12	1,167.49**
Among 3	15	487.88**
Among 4	15	804.32**
5 vs. 6	1	2,387.02**
Entries x Rates	62	112.45**
0, 1, 2, 3, 4 vs. 5, 6 x R	1	172.20**
0 vs. 1, 2, 3, 4 x R	1	10.51
1, 2 vs. 3, 4 x R	1	140.82*
1 vs. 2 x R	1	9.56
3 vs. 4 x R	1	337.85**
Among 0 x R	2	49.05
Among 1 x R	12	102.99**
Among 2 x R	12	116.32**
Among 3 x R	15	140.68**
Among 4 x R	15	85.92**
5 vs. 6 x R	1	172.23**
Entries x Years	62	76.69**
0, 1, 2, 3, 4 vs. 5, 6 x Y	1	1.08
0 vs. 1, 2, 3, 4 x Y	1	0.21
1, 2 vs. 3, 4 x Y	1	512.50**
1 vs. 2 x Y	1	0.35
3 vs. 4 x Y	1	339.30**
Among 0 x Y	2	406.62**
Among 1 x Y	12	70.63**
Among 2 x Y	12	61.66**
Among 3 x Y	15	44.79**
Among 4 x Y	15	51.10**
5 vs. 6 x Y	1	62.50**
Entries x Rates x Years	62	22.67*
Pooled error (c)	992	14.99

\*Significant at the 5% level.

\*\*Significant at the 1% level.

each rate. Estimates of the variance components for among lines, lines x years, and error are shown in table 15.

The error component estimates were larger at the 24,000 population level than at the 12,000 population level for all groups of lines. The among-lines component, also, was larger at rate 24,000 for all groups; the increases were relatively greater for the among-line component than for the error component in all except group 2 where the relative increases were essentially equal. The line x year component increased from rate 12,000 to rate 24,000 in all except group 3. An increase of the line x year component was not an important consideration in these experiments because of large differences among lines, but it may be an important consideration where line differences are smaller.

Table 15. Estimates of components of variance and heritability values for yield of four groups of selections compared at two rates of plant density in 1964 and 1965.

	12,000				24,000			
	$\hat{\sigma}_L^2$	$\hat{\sigma}_{LY}^2$	$\hat{\sigma}^2$	H	$\hat{\sigma}_L^2$	$\hat{\sigma}_{LY}^2$	$\hat{\sigma}^2$	H
Group 1 . . . . .	18.04	2.42	13.74	0.87	54.44	8.48	21.51	0.89
Group 2 . . . . .	35.66	1.68	9.90	0.95	74.25	9.12	20.09	0.92
Group 3 . . . . .	7.47	4.68	9.74	0.69	48.71	3.26	17.65	0.93
Group 4 . . . . .	19.63	3.48	6.76	0.89	60.26	9.53	18.74	0.90

Heritability values are more significant than individual component estimates in evaluating testing procedures. Our heritability values (table 15) indicate that evaluations of the lines were equally effective at the two stand levels, except for group 3 in which evaluation was more effective at the higher stand level. Group 3 lines were developed by selection in successive generations at a low-stand level. Yield data in table 13 show that several lines in group 3 had a yield potential that was not revealed under the 12,000 population level. Line component estimates indicate similar situations in groups 1, 2 and 4, but to a lesser extent than in group 3.

#### Ear Shoot Development of the Inbred Lines

Ear shoot development of the inbred lines was studied to determine if selections developed by different breeding procedures may be characterized by differences in rate of cob elongation, particularly in the case of the second cob.

The data obtained in the measurements of cob elongation in the period of 15 to 18 days before silk emergence closely approximated a semilogarithmic curve, log ear length versus time. Since over 90 percent of the cob growth could be explained by the semilogarithmic relationship, the raw data were converted to the semilog form for presentation and analysis. The single major exception to the otherwise consistent pattern was the second ear of C103 that failed to develop in 1964 as it did in 1963.

The growth rates of the entries (selections by groups) in terms of their regression coefficients are presented in table 16. An analysis of variance of group and parent regression coefficients indicated that the differences among b values in 1963 were not significant but that, in 1964, the differences among b values for both top and second cobs were significant ( $p < 0.01$ ).

Comparing b values for the five highest and five lowest combining lines, the growth rates were greater for both cobs of the high-combining lines; however, the difference was greater for the second cob. The data suggest a relationship between combining ability and growth rate of the second cob. Group 3 lines had higher b values than group 4 lines for both top and second cobs; the testcross mean yield was higher in group 4 than in group 3. Group 0, which had the highest combining ability among the groups, had high b values that were nearly equal. Except for the parent lines, b values for individual lines were not computed because inadequate sampling resulted in



imprecise estimates. The hybrid vigor of the single cross, M14xC103, was not expressed in a faster growth rate of either cob. Its greater cob length at date of silking was probably caused by an earlier commencement of cob development.

Table 16. Regression coefficients, *b*, of log cob length with time for the two top ears during the two weeks preceding silking and cob length at date of silking.

Entry	1963		1964	
	Top cob	Second cob	Top cob	Second cob
	<i>b</i>	length cm	<i>b</i>	length cm
Group 0			0.071	12.9
Group 1			0.063	13.5
Group 2			0.062	13.3
Group 3	0.078	12.8	0.072	8.5
Group 4	0.074	13.5	0.071	9.4
M14	0.066	12.2	0.057	8.1
C103	0.085	12.5	0.055	2.5
M14xC103			0.059	10.4
All selections	0.076		0.065	
5 highest combiners			0.072	14.6
5 lowest combiners			0.066	13.7
Standard error <i>S<sub>b</sub></i>	0.004		0.005	

#### Correlation Studies

If ear development of an inbred line is associated with vigor, the rate of cob development, cob length at silking and seed yield should be associated with combining ability. In this study, sampling was not adequate for growth rate studies on an individual line basis, but final measurements of cob length at date of silking used larger samples; each line had 10 plants per replication, for a total of 30 measurements. The final length of the second cob was a close approximation, relatively, to the *b* value for rate of cob development. Also, the ratio of the second cob length to the top cob length at silking would be indicative of the growth rate of the second cob and the total vigor of the line insofar as the female inflorescence is concerned. These data made practical a number of phenotypic correlations with hybrid yield. In addition, plant height and date of silk emergence of the inbreds were correlated with their yield performance in testcrosses.

The correlation coefficients calculated for the relationship of six inbred attributes with hybrid yield are presented in table 17. Four *r* values are positive and highly significant; two are not significant. The significant *r* values are too low to be of predictive value, but they do show positive relationships. The length of the second cob had a highly significant correlation with hybrid yield, but the first cob length had no relationship. There was a tendency for the taller lines to give greater hybrid yields, although this was not an exclusive situation. It is expected that climatic conditions for at least four of the hybrid tests would favor the earlier hybrids, thus resulting in a negative correlation of date silked with hybrid yield.

Table 17. Phenotypic correlation coefficients between agronomic characters of the inbred selections and their average yields in hybrid combinations.

Inbred character	<i>r</i> -value with hybrid yield
Top cob length <sup>a</sup>	0.09
2nd cob length <sup>a</sup>	0.34**
Ratio of cob lengths <sup>b</sup>	0.32**
Yield	0.35**
Plant height	0.37**
Date silked	-0.10

<sup>a</sup> at date of silk emergence.

<sup>b</sup> ratio = 2nd cob length/top cob length.

\*\*Significant at the 1% level.

#### DISCUSSION

When these evaluation experiments were planned, we hoped that variation among the environments would exist such that in at least some environments the highest grain yields would be obtained at the highest population levels. Such environments did not exist among the 10 sampled, although individual testcrosses did produce more grain at the 24,000 population level than at either the 12,000 or 18,000 population level at Ankeny in 1965. Differences among the testcrosses in performance across population levels suggest that the yield potential of the genotypes studied, which includes the testers, could have been a limiting factor. The lower yields at 24,000 may have been caused by insufficient nutrients in some locations, but in all cases, it is believed that moisture stress at some period during grain development was the more important factor. Variation among environments was great, however, as was expressed by the differential depression of grain yields at the higher rates. Consequently, the comparisons obtained may be reasonably applicable to situations where higher yields are obtained at high plant densities.

Perhaps we need to consider first if the lines evaluated represent only a random sample from the *F*<sub>2</sub> of M14xC103, or if some positive gain has been achieved. Since the source was M14xC103, it seems logical that the testcross of M14xC103 is the proper check with which to make comparisons. Group mean yields indicated that positive gains were made in groups 0, 1, 2 and 4 but not in group 3. If the L.S.D. at the 5-percent probability level is used as a criterion, the number of lines whose testcrosses exceeded the testcross of M14xC103 were three, four, five, five and four in groups 0, 1, 2, 3 and 4, respectively; and the number of lines with testcrosses less than the testcross of M14xC103 were zero for groups 0, 1 and 2, three for group 3, and one for group 4. The number of testcrosses exceeding the check was 34 percent, which is considerably greater than expected on the basis of random sampling. If these comparisons are accepted, progress was achieved in all groups, but visual selection at a low-stand density was less effective in eliminating genotypes with low combining ability. The progress was greater in groups 1 and 2 than in groups 3 and 4, which should have been expected if there had been some selection for specific combining ability with tester WF9xI205. The composite tests with the unrelated tester indicated that the greatest gain was in group 4,



with no gains in groups 1 and 3. Variation in yields among the groups with the unrelated tester would be a reflection of difference in selection for additive gene effects, and the data show more effective selection in group 4.

Jenkins (1935) proposed early testing as a means of identifying superior genotypes in the early 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 was possible for three generations after the first. The data obtained in the present study have shown that the testcross procedure produced lines that yielded more than the testcross of M14xC103; 12 of 29 lines in testcrosses yielded more than the source testcross by a margin exceeding the L.S.D. at the 5-percent level of probability, and none yielded less. Sprague and Miller (1952) found no positive gain in combining ability for successive generations where visual selection was practiced among and within inbred progenies. Our evaluations of the lines in groups 3 and 4 did indicate that visual selections among and within inbred progenies resulted in a positive gain for combining ability. We cannot determine from these studies whether the gain in performance was mostly in the earlier generations of selection, or if it was a gradual process over the generations in which selection was practiced.

The original hypothesis, the basis for this extended study, was that inbred lines selected on the basis of their performance in dense populations will be superior in both high- and low-population densities, but that lines selected on the basis of their performance in low populations may not necessarily be superior at high-population densities. The testcross performance of M14 and C103 in the present study indicate that they are typical of the two types of lines suggested in the hypothesis, although we do not know the selection methods used in the development of M14 and C103. The data presented here comparing the performance of M14 and C103 testcrosses at different population densities confirm earlier data, which was the main reason for selecting M14xC103 as the source from which to develop materials to test the hypothesis.

If the procedures used to develop the inbred materials resulted in genotypes whose performances would support the hypothesis, then the evidence should be available in group comparisons. In table 18, we show the composite yields at population levels 12,000 and 16,000 versus 24,000 and 28,000, averaged over 10 environments and two testers. The yields of groups 1 and 2 were equal at the lower stand densities, but at the higher stand densities group 2 yielded more than group 1. Comparing groups 3 and 4, the yield data support the hypothesis more strongly because group 4 yielded more at both stand densities. Similar group comparisons at the 12,000 and 24,000 population levels where individual testcrosses were evaluated give some support of the hypothesis, but more strongly for groups 3 and 4 than for groups 1 and 2. The data suggest that selection at high-stand levels will result in better combining ability regardless of the rate used in subsequent testing.

Table 18. Mean yields for four composites averaged over two testers and 10 environments at the two lowest- and two highest-population levels.

Composite	Mean yields at population levels		
	12,000 and 16,000	24,000 and 28,000	R <sub>I</sub>
Group 1 . . . . .	57.2	46.0	-3.55
Group 2 . . . . .	57.4	48.0	-3.00
Group 3 . . . . .	54.6	43.6	-3.63
Group 4 . . . . .	56.9	46.5	-3.15

Another comparison would be to select the top five yielding testcrosses in each group as follows: groups 1 and 3 tested at 12,000 plants per acre and groups 2 and 4 tested at 24,000 plants per acre, and compare the mean yields for these population levels. These data, table 19, give evidence to support the development of inbred lines under the population levels at which they will be used, rather than supporting the hypothesis. Furthermore, the group comparisons over population rates, in the tests of composites and tests of individual testcrosses, such as group 1 vs. group 2 x rates linear, did not give significant F values. However, the groups selected at high-stand levels had lower negative linear regression values than did the groups selected at low-stand levels.

Table 19. Mean yield at the 12,000 and 24,000 population levels for the five highest-yielding testcrosses in groups 1 and 3 selected at the lowest-stand level and the five highest-yielding testcrosses in groups 2 and 4 selected at the highest-stand level.

Composite	Mean yields at population levels		
	12,000	24,000	R <sub>I</sub>
Group 1 . . . . .	63.4	57.9	-2.75
Group 2 . . . . .	61.8	61.6	-0.10
Group 3 . . . . .	63.6	61.1	-1.25
Group 4 . . . . .	61.7	62.0	+0.15

We did not obtain results that support the hypothesis to the extent of the contrast between the performances of M14 and C103. Perhaps this should have been expected because of the extensive testing involved in developing the inbred lines. The inbreds of groups 1 and 2 were selected in three successive generations on the basis of testcross performance. Except for the first generation, the testcrosses were grown in four environments in each generation. Climatic conditions would be different among the environments such that in some locations stress conditions at a 16,000 stand level would be equivalent to a 24,000 stand level in some other locations. Thus, the variation in environmental conditions during the development of inbreds in groups 1 and 2 may have induced the stress effects that we attempted to introduce by using low- and high-stand levels. Consequently, the genotypes selected at 16,000 population may not be greatly different from the genotypes selected at 24,000. We have no evidence, either in the phenotypic appearance of the lines



or in the performance of the inbreds per se, to suggest that group 1 selections should resemble C103 in performance and group 2 selections should resemble M14.

The inbreds of groups 3 and 4 have a distinct difference in plant height, except for a few selections, presumably because of some difference in selection pressure at low- and high-stand densities. Group means for testcross performance showed more progress in group 4 than in group 3 because of a difference in the number of low-yielding genotypes in the two groups. The data obtained for these groups supported the hypothesis in the tests of composite testcrosses, but the support was less definite in individual testcrosses. Phenotypic selection was rigid in both groups, and over several generations most of the unfavorable genotypes were eliminated. For example, the percentage of barren stalks in groups 3 and 4 did not differ although selection for this character was greater in group 4 than in group 3. The frequency of genes responsible for barrenness may have been reduced significantly in group 4 after only one or two generations, whereas the same success may have been accomplished in group 3 in the four generations of selection.

We did not have a superior yield environment during the evaluation of these materials. If selection at high-stand levels is successful in isolating genotypes that have greater yield potential than possessed by genotypes selected at low-stand levels, then we should expect the greater yield potential to be demonstrated in the superior yield environment. In a low-yield environment, environmental factors limit grain yield, but in a superior-yield environment, grain yield is limited by the genotype of the plant. The best yield environment for our experiments was at Ankeny in 1965. However, the data obtained at this site did not support the hypothesis any better than the results already presented considering all environments. Similar comparisons under irrigation where soil moisture would not be a limiting factor at any time during the growing season could provide useful information.

The three lines of group 0 were selected on the basis of superior performance at both high- and low-stand levels, and these lines exhibited above-average yield performance in the present evaluations. This is evidence for the advantage of extensive testing; however, if a program cannot permit the luxury of developing and testing materials at several population levels, the data support the use of a high- rather than a low-stand level.

This study provides an excellent opportunity to compare two methods of inbred development: selection based on testcross performance versus selection based on inbred phenotype. The lines of groups 1 and 2 have an advantage in this comparison in the tests of individual testcrosses because the tester parent was the same as used in the development of these lines. In spite of this advantage, however, the phenotypic selection of inbred lines resulted in genotypes that were equal in combining ability to the best genotypes selected on the basis of testcross performance. The highest-yielding line was in group 4; selection 58 yielded 3.2 cwt more than the best testcross, 18, in the testcross groups, and in inbred yields 58 exceeded 18

by 7.8 cwt. When the comparison is made for the unrelated tester in the composite data, group 4 was better than either groups 1 or 2. Thus, for the genotypes investigated here, phenotypic selection of the inbreds in a stress environment has been as effective as selection by testcross performance. Furthermore, the progress in group 4 has been accomplished at much less cost and in a shorter time. If phenotypic selection at a high-stand density were used, the initial sample would be larger than available here, and one could expect even greater progress.

Grain yields and percentage barren stalks of the five highest- and five lowest-yielding testcrosses are shown in table 20. These lines were selected on the basis of their mean testcross yields over all rates and environments. Sources of the five high lines were as follows: group 1, one; group 2, one; group 3, two; group 4, one; and for the five low lines, group 3, four and group 4, one. The high group had its greatest yield at the 18,000 population level and the low group, at the 12,000 population level. The low group did not have the genetic potential to take advantage of more plants per acre, even at the moderate rate of 18,000 plants per acre. Yield difference between the high and low groups was 8.9 cwt at rate 12,000, but this increased to 19.5 cwt at rate 24,000. The low group had almost fourfold more barren stalks at the high-stand level than was shown for the high group. Since barren stalks were negligible in both groups at the lowest-stand level, the low group must have yielded less because of smaller ear size, or smaller seed size, or both.

Table 20. Grain yields and percentage barren stalks for the five highest- and five lowest-combining selections for two years.

Selection number	Yield, cwt per acre at population density (x1000)				Mean	R <sub>1</sub>	Percentage barren stalks
	12	18	24	Mean			
58. . . . .	64.4	71.7	69.9	68.6	+2.75	3.2	
43. . . . .	62.8	73.9	66.0	67.6	+1.60	3.9	
18. . . . .	64.0	68.1	64.2	65.4	+0.10	4.8	
44. . . . .	65.4	69.2	61.4	65.3	-2.00	6.8	
15. . . . .	65.4	69.8	60.6	65.3	-2.40	4.5	
Mean. . . . .	64.4	70.5	64.4	66.4	0.00	4.6	
34. . . . .	58.3	55.3	50.3	54.6	-4.00	15.8	
47. . . . .	54.7	56.9	46.8	52.8	-3.95	16.4	
41. . . . .	55.8	56.5	46.7	53.0	-4.55	15.8	
32. . . . .	53.8	53.9	45.1	50.9	-4.35	14.3	
35. . . . .	55.0	47.7	35.8	46.1	-9.60	22.7	
Mean. . . . .	55.5	54.1	44.9	51.5	-5.30	17.0	

As an adjunct to the testcross data, agronomic data for the inbred progenies of the same lines are shown in table 21. The high group had a mean inbred yield of 33.7 cwt as compared with 22.3 cwt for the low group. A part of this yield difference can be accounted for by the greater incidence of barrenness in the low group. Yields of the inbreds and testcrosses in the two groups suggest that the correlation between inbred and testcross yields should be higher than the



value of 0.35 obtained when all lines were considered. The difference in plant height between the two groups was large and indicated a definite advantage for the taller types. The low group was later than the high group in days to silk.

Table 21. Agronomic data<sup>a</sup> for the inbred lines per se that were the five highest and five lowest in combining ability.

Selection number	Yield, cwt/acre	Plant height, cm	Days <sup>b</sup> to silk	Percentage barren stalks
58.....	39.4	169	32.5	2.3
43.....	31.1	142	33.2	2.8
18.....	31.6	140	31.4	0.7
44.....	32.4	128	31.7	6.4
15.....	33.9	137	32.5	4.6
Mean.....	33.7	143	32.3	3.4
34.....	16.7	101	31.9	14.0
47.....	19.0	120	32.6	9.8
41.....	22.0	134	35.8	13.1
32.....	23.3	120	32.0	12.1
35.....	30.3	137	34.7	8.8
Mean.....	22.3	122	33.4	11.6

<sup>a</sup> Data averaged for 12,000 and 24,000 population levels.

<sup>b</sup> Days after July 1.

Our evaluations were for 61 inbred selections developed from an original sample of 95  $F_2$  plants. There were 29 lines in groups 1 and 2, and three of these lines belong to both groups. Among the remaining 13 lines in each group, six lines of group 1 had common  $F_2$  origins with six lines of group 2; thus 23 descendants of the original  $F_2$  plants were represented in these two groups. This supports a suggestion made earlier that the genotypes selected on the basis of testcross performance at 16,000 population may not be greatly different from the genotypes selected at 24,000 population. Among the 16 lines in each of groups 3 and 4, three lines from each group had common  $F_2$  origins; or 29 of the original  $F_2$  plants were represented in those two groups. Genetic relationships, based on  $F_2$  origin, are less between groups 3 and 4 than between groups 1 and 2, as was suggested previously. Six lines of the testcross groups and six lines of the visually selected groups descended from six  $F_2$  plants; one  $F_2$  plant was the origin of one group 0 selection and selection 58 in group 4. Since all lines in all groups were selected without reference to what was being selected in the other groups, it appears that visual selection and testcross selection were based on some of the same attributes. Forty-six of the original  $F_2$  plants were represented in our evaluations, 29 in the visually selected groups and 23 in the testcross groups with six lines of each group descended from six  $F_2$  plants.

Probably the most significant information obtained from these studies was in the results of the inbreds per se. Visual selection among and within progenies was very effective in improving seed yield in group 4. Group 4 lines had a mean yield of 28.4 cwt as compared with 25.8 cwt for M14 and 10.3 cwt for C103.

The mean yield for group 3 was equal to M14 but superior to the mean of the parents. There were five lines in group 3 and seven lines in group 4 that yielded greater than M14 by at least one L.S.D. at the 5-percent level of probability. The mean yield for selection 58 exceeded M14 by more than 50 percent, a phenomenal increase in only one cycle of breeding. Selection under stress conditions of high population density was effective in combining vigor genes from C103 with genes for high seed yield in M14 to give new selections that were much superior for seed yield. In contrast, the mean yields of groups 1 and 2 were less than M14 but were above the mean of M14 and C103. Only two lines in group 1 and three lines in group 2 yielded significantly greater than M14. High seed yields of inbred lines are necessary for single-cross seed production to be profitable. The results of this study have shown that inbred seed yields can be improved significantly if proper selection pressures are used during the developmental generations.

Progress reported in this study for improved seed yield of inbred lines has been much greater than reported in some self-pollinated crops (Atkins, 1964; Frey, 1962, 1964). Since selection in the self-pollinated crop has always been for yield at the inbred level, the production realized may be approaching the limit permitted by the genes available in the sources used for parental material. Consequently, even small additional increments are very difficult to obtain. By contrast, corn breeders have emphasized performance in hybrid combinations. High-combining inbreds have been acceptable if they could be maintained and used with little difficulty to produce single crosses that were used to produce double crosses. The ceiling for maize inbred seed yield may be considerably higher than any lines yet available. If overdominance and dominance types of epistasis are not of any significance in controlling grain yield in corn hybrids, it will be possible to develop a corn inbred line whose yield would approach the better hybrid yields.

Gotoh and Osanai (1959b) obtained more progress in wheat when selection was done at a low soil fertility. This could be considered better selection under nutrient stress, and the results of the present study would be similar because available nutrients per plant would be less at the high-stand level than the low-stand level. By contrast, however, Gotoh and Osanai (1959a) reported more efficient selection of wheat under a low-plant density because of increased phenotypic variation. In our study, the variance among lines increased at the higher stand level in the replicated experiments. If the same situation existed in the selection nurseries, greater progress could be expected at the higher stand levels. It was explained in the introduction that stress to maize may be considered from two aspects: yield per plant and yield per unit area. Inbred selection at a density of 12,000 plants per acre would permit almost maximum expression of the yield potential per plant. By contrast, inbred selection at 24,000 plants per acre would be giving strong consideration to the maximum yield per unit area. Our data show that it is more desirable to select for maximum yield per unit area, especially in the improvement of inbred yield per se.



Inbred selection at the high-stand density had one important disadvantage in this study: Lines selected at the high-stand level have greater plant height than lines selected at the low-stand level. The reason for this difference is not readily evident unless there is a positive association between plant height and the ability of a plant to produce silks concurrently with pollen dehiscence when grown in dense stands. This may not be the reason, however, because M14 is short and has good silk emergence, whereas C103 is tall and has poor silk emergence. In the higher population nursery, the short plants may have been at a competitive disadvantage and unable to show a good plant development and seed yield. Consequently, they would have been eliminated in the early segregating generations. If the corn breeder develops inbred lines under conditions of high plant population, he must emphasize selection for short stature. The greatest difficulty in selection for short stature would be in the first two segregating generations when there would be segregation for plant height in the progeny row, and plant-to-plant competition would be at a maximum. If the first two segregating generations were grown at a low-plant density where competition between plants would be small, shorter genotypes would develop better and could be selected. Then selection in subsequent generations could be done at higher population levels, using mul-

tle row plots if necessary to eliminate competition between progenies with different plant heights.

The results of this study did not give indubitable support to the hypothesis that was the original basis for the research. The data do suggest that it would be desirable to develop the inbred lines at a higher plant population density. We do not know what variations may be obtained if narrower row spacings should be introduced. Extensive studies involving genotypes, row spacings and population densities are needed. The inbred materials were developed from a specific source, single-cross M14xC103, the parents having been chosen because of their contrast in performance at different population levels. Perhaps different results would be expected if materials were developed similarly from a synthetic variety. The data indicate that a corn inbred used in high populations must have silks emerge concurrently with pollen dehiscence to prevent barrenness under stress conditions. Cob-development data suggest that selection toward an inbred type with strong second-ear growth would be desirable. Consequently, the question arises: Should inbred selection be at a high-stand level where second ears will not be produced, or should selection be at a low-stand level and preference given to the two-ear type? Research to answer this question is now in progress.

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