

A DIALLEL STUDY OF FLOWERING AND OF EAR COMPONENTS OF YIELD IN CORN BELT  
MAIZE AND THEIR INTERACTIONS WITH POPULATION DENSITY

by

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(ABSTRACT)

A diallel study of American Corn Belt maize (Zea mays L.) was conducted at Holland, Virginia in 1981 and 1982. All possible crosses of twelve inbred parents (A619, A632, B73, H60, H93, H96, Mo17, Oh7B, Pa91, Va17, Va.79:419, Va85) were planted in three replications with population density treatments of 39,536, 49,420, 59,304, and 69,188 pl/ha in strips across hybrid treatments. Analyses of variance and combining ability analyses were performed on traits measuring the timing of anthesis (pollen shed) and silk emergence, on ear components of yield, and on components of kernel size. Density effects were highly significant for all traits, except for that of pollen shed duration, in the analyses combined over years. Hybrid-by-year interactions were highly significant for all traits. Correlations between GCA effects of grain yield and GCA effects of silking delay (anthesis-to-silking interval), kernels per row on the ear, ear kernel number, and kernel depth  $[(\text{ear diameter} - \text{cob diameter})/2]$  were -0.79, 0.64, 0.66, and 0.80 in 1981, and 0.24, 0.81, 0.71, and 0.26 in 1982, respectively. Moisture stress sufficient to cause wilting occurred before and during silking in 1981. Apparently, short silking delay

was associated with high moisture stress tolerance for grain yield in 1981 and was associated with long ear shoot length in 1982. Deep kernel depth apparently was associated with drought stress tolerance for yield as well. The heritabilities of ear traits were higher the earlier they became established in the sequence of development. Heritabilities of silking delay and most ear components of yield were increased by increasing planting density. However, the correlations among flowering and ear traits largely were unaffected by density, perhaps because densities were not high enough to make barrenness a substantial factor in grain yield. The most important traits related to yield were silking delay, kernels per row, kernel depth, and kernel row number. GCA to SCA variance component ratios were increased by combining data over years and by the more optimum season for yield.

Key words: drought, combining ability

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## INTRODUCTION

Corn Belt dent maize (Zea mays L.) originated in what is now the eastern part of the USA Corn Belt during the 19th century with the deliberate crossing of cultivars from two racial complexes, white Southern dents and long eared Northern flints (Brown and Goodman, 1977). Prior to the introduction of Corn Belt dents, the Southern dents, related to the Mexican dent complex, were grown in the southeastern United States as far north as northern Virginia and Maryland. In the northeastern United States the Northern flints predominated. American hybrid maize originated from crosses of inbreds derived by selfing Corn Belt dent cultivars. Hybrid maize research has been centered in the Corn Belt where yield potential is highest. Elite U.S. germplasm has, therefore, tended to be adapted to Mid-west conditions. Since genetic advancements in yield potential have become less frequent, more importance must be placed on adapting maize to specific regions.

Unlike soils in the Corn Belt, those in Virginia are shallow with low water holding capacity and fertility. Recent rainfall patterns are more important than stored soil moisture in Virginia and untimely drought is the leading cause of yield loss. Therefore the purposes of this study were:

1. to provide general information on the relative adaptability of elite Corn Belt maize to the climate and soil of Virginia;
2. to measure the genetic differences among a large number of hybrids for anthesis-to-silking interval and other traits associated with timing of flowering events, ear and kernel components of yield, and grain yield;
3. to calculate general and specific combining ability estimates of all traits for the inbred parents and individual hybrids;
4. to measure the effect of population density on each trait and the effect of density on the ability to discriminate differences among hybrids for the trait;
5. to measure the genetic relationship between traits and to assess the relative value of each trait in selecting for grain yield potential;
6. to measure the effect of density on the expression of genetic relationships among traits;
7. to calculate the heritabilities of each trait and to measure the influence of population density on the heritabilities;and



8. to estimate the influence of season on all traits and to measure the possible interactions of season and density effects.

A diallel mating design using twelve inbred parents representative of elite Corn Belt maize was chosen as the best scheme for generating a large number of hybrid cultivars to test.

The study complements the study conducted by Christopher O. Perry who studied stalk rind strength and its association with yield and standability (Perry, 1983). This study examined events critical to flowering and their effect on grain yield and ear components of yield. Among the events studied was delay of silk emergence relative to pollen shed, a phenomenon commonly recognized as an early indicator of grain yield loss.

## REVIEW OF LITERATURE

### PLANTING DENSITY

The development of cultivars that can make maximum use of higher planting densities is one of the most important aspects of modern maize breeding. This has not always been the case. The introduction of hybrid cultivars in the 1930's, and the dramatic increase in the use of nitrogen fertilizer beginning in Iowa about 1947 (Zuber et al., 1954), placed emphasis on the interaction among genotypes, nitrogen fertilization rates, and planting densities.

Experimentation on maize planting densities in the United States began soon after the Civil War. These early results on open-pollinated cultivars in the Corn Belt confirmed the superiority of the check-rowed method (planting in hills at the intersections of perpendicular arrays of rows) over the drilled-row method, due to the ease of cultivation and the stability of yield under conditions of drought and poor soil fertility. Fertilizer was found to have little effect on increasing grain yield except with seriously depleted soils (Morrow and Hunt, 1891; Hume et al., 1908; Latta, 1889). Increasing planting density above the standard 20,000 pl/ha to 30,000 pl/ha (8,000 to 12,000 pl/a) was found to increase yield but reduce ear size. Cultivars differed with respect to the population density at which maximum grain yield was produced, but generally plots

with 250 gram (half-pound) ears produced maximum yield(Mooers, 1920; Latta, 1889). Data on recently released germplasm suggest that optimum ear size has decreased to about half that of the earlier germplasm(Rutger and Crowder, 1967). Shorter-season cultivars produced maximum yield at higher population densities than longer-season cultivars(Hume, et al., 1908; Mooers, 1920). Richey(1933) summarized the results of previous experiments and concluded that the optimum stand density is greater with smaller plants, with higher latitudes, and with higher soil moisture and fertility. Cultivar differences were considered relatively unimportant in determining optimum stands.

Experimentation on hybrid cultivars introduced in the late 1930's showed that grain yields were increased by the new cultivars(Bryan et al., 1940). It rapidly became clear that the superiority of hybrids over open-pollinated cultivars was attributable to the planting density tolerance of the hybrids(Haber, 1944; McVickar and Shear, 1946; Dungan, 1946; Stringfield and Thatcher, 1947). The superiority of drilled-row planting increased as planting density increased(Enzie, 1942; Colville and McGill, 1962). Drilled-rowed and equidistantly spaced plots were found to silk from one to several days earlier than did hilled plots(Kohnke and Miles, 1951). Date of silking was delayed one day for each additional 7,500 to 10,000 pl/ha(Lang et al., 1956) and anthesis-to-silking interval was increased by 0.8 days(Edmeades et al., 1979).

Fertilizer applications, especially nitrogen applications, were found ineffective in increasing yield at low population densities and in a poor season (Seem and Huber, 1947; Jordan, et al., 1950). Differences among hybrids for grain yield in response to planting density were apparent only with high soil fertility (Duncan, 1954). Maximum grain yield involves efficient plant nitrogen utilization and grain yield is maximum when percent nitrogen of grain is lowest (Zuber et al., 1954; Prince, 1954; Lang et al., 1956; Thomas, 1956; Russell and Pierre, 1980; Kamprath et al., 1982). Sanford et al. (1965) found that substantial plant-available nitrogen was used in pollen production and that this nitrogen utilization restricted ear development. Silking interval and tassel weight were negatively correlated (Mock and Buren, 1972). The correlations between anthesis-to-silking interval and ear diameter, kernel depth, kernel weight, and ears per plant were improved by reducing nitrogen rates (Balko and Russell, 1980).

Ear abortion and kernel abortion from the tip were greatly increased by shading, suggesting that density tolerance is actually shade tolerance. The major immediately visible factor influenced by shading was rate of silk development, which was reduced substantially (Stinson and Moss, 1960; Moss and Stinson, 1961; Prine and Schroder, 1964; Earley et al., 1966). Nitrate reductase activity was greatly reduced by shading (Hageman and Flesher, 1960), as was total plant protein (Earley et al., 1966). Reduced light intensity resulted in kernel abortion from the ear tip despite ad-

equate carbohydrate reserves(Struik and Deinum, 1982), suggesting the function of a regulatory mechanism for adjusting seed set to projected resource availabilities based on plant-to-plant competition. Improving photosynthetic efficiency did not result in greater density tolerance(Muleba and Paulsen, 1983).

No effect of planting density on female floret primordia development was found(Edmeades and Daynard, 1979; Iremiren and Milbourn, 1980). Sass and Loeffel(1959) found that ear shoot and silk development was two to three times faster at 30,000 pl/ha (12,000 pl/a) than at 59,000 pl/ha (24,000 pl/a). Silking rate was more variable and a pronounced bimodality in development, with a distinct group of plants going barren, was apparent at high planting densities(Edmeades and Daynard, 1979). Differences in tendency toward barrenness was the major factor in density tolerance(Iremiren and Milbourn, 1980). Hybrids tolerant of density were also found tolerant of uneven spacing due to more ears per plant(Hoff and Mederski, 1960; Pintér et al., 1979b; Pintér, 1980). A strong association between large anthesis-to-silking interval and barrenness existed (Woolley et al., 1962; Mock and Buren, 1972). Cultivars that performed well at low planting densities tended to produce long single ears. Those that performed best at high planting densities tended to be two-eared types which exhibit less barrenness(Lang et al. 1956; Collins et al., 1965; Russell, 1968). The grain yield of prolific cultivars declined at intermediate planting densities(Collins et al., 1965; Collins and

Russell, 1965; Russell, 1968). Apparently, either late abortion of the second ear or a nubbin second ear disrupts the development of the primary ear. Duncan(1958) found that the log of per-plant grain yield plotted against planting density was linear.

Significant hybrid-by-density interactions have been found for yield and ears per plant(Rutger and Crowder, 1967; Poneleit and Egli, 1979). Phenotypic selection and selection for small anthesis-to-silking interval among inbred lines were as effective as test-cross selection for grain yield and produced better lines per se(Russell and Teich, 1967). Test-cross selection for grain yield of synthetic cultivars, hybrids, and inbred lines produced positive response for density tolerance when germplasm was evaluated at densities above the optimum for grain yield(Russell and Teich, 1967; Russell, 1969; Fakorede and Mock, 1978). Density tolerance was unaffected by selection at low densities except where prolific germplasm was used(Moll and Kamprath, 1977). Advances in grain yield throughout the history of hybrid maize were substantial(0.067 Mg/ha/y) when hybrids were evaluated at 44,000 pl/ha, but improvements were negligible when tested at 32,000 pl/ha(Duvick, 1977). The correlations based on inbred means between grain yield and anthesis-to-silking interval and between grain yield and ear components of yield were improved substantially by increasing planting density from 77,000 pl/ha (31,000 pl/a) to 146,000 pl/ha (59,000 pl/a). The correlations based on hybrid means and general combining ability(GCA) effects between anthesis-to-

silking interval and grain yield were nonexistent at 30,000 pl/ha (12,000 pl/a), but were very highly negative at 244,000 pl/ha (98,800 pl/a) (Mock and Buren, 1972; Buren et al., 1974). Barrenness and anthesis-to-silking interval were highly positively correlated at the high density. Genetic differences in density tolerance were more easily discriminated in inbred lines than in hybrids.

Differences in mean hybrid grain yields in response to high planting densities were the result of more kernels per land area (Hanway and Russell, 1969; Fawusi and Wanki, 1982) larger kernel size and weight (Daynard et al., 1971; Poneleit and Egli, 1979), or both (Wilson and Allison, 1978). The major effect of post-pollination thinning was an increase in kernels per row on the ear (Baenziger and Glover, 1980). Most ear abortions occurred after 50% silking (Prine, 1971). Ear size and number per plant were found more limiting at lower latitudes (Tollenaar, 1977).

#### DROUGHT TOLERANCE

Drought tolerance in maize has not received as much study as other aspects of maize production. The "dust-bowl" drought, centering around 1936, stimulated interest in breeding for drought tolerance, but despite occasional seasons of poor rainfall in the Central Corn Belt, great interest in drought tolerance remains centered in dryland regions.

The effect of season was considered the factor most important to grain yield in early studies(Latta, 1889; Morrow and Hunt, 1891). Both accumulated soil moisture and the absence of long periods without rain were essential to maintaining grain yield(Basile, 1954). Nitrogen application(Alessi and Power, 1965; Shaw and Felch, 1972), increasing population density(Mooers, 1920; Huber, 1944; Richey, 1933; Woolley et al., 1962; Seem and Huber, 1947), or both(Thomas, 1956; Carlson et al., 1959) had positive effects on grain yield only when soil moisture was adequate. Multiple plants per hill and widely spaced, closely planted rows produced greater grain yields under moisture stress(Morrow and Hunter, 1891; Collins and Shedd, 1941; Dungan, 1946).

The period just prior to and during silking was the most sensitive to moisture stress with respect to grain yield(Miller and Duley, 1925; Robins and Domingo, 1953; Denmead and Shaw, 1960; Barnes and Woolley, 1969; Holt et al., 1964; Claassen and Shaw, 1970a and b; Moss and Downey, 1971). The earlier moisture stress occurred in vegetative development, the less the effect on grain yield(Miller and Duley, 1925) and recurrent periods of stress had progressively less effect(Barnes and Woolley, 1969).

Aberrant ovule and embryosac development was observed with wilting during early ear shoot development(Claassen and Shaw, 1970a and b; Moss and Downey, 1971). Moisture stress just prior to and during silking resulted in reduced kernels per row on the ear due to spotty floret abortion, as



well as abortion from the ear tip (Hall et al., 1981), and stress a few weeks after silking resulted in reduced kernel size (Claassen and Shaw, 1970a and b; Downey, 1971). Silking was delayed up to 16 days by moisture stress during embryosac development (Moss and Downey, 1971). Moisture stress just prior to pollen shed was most effective in increasing anthesis-to-silking interval. Pollen shed duration was increased by stress during tasseling, but total pollen grains shed was reduced (Hall et al., 1982). Silk elongation followed closely the daily cycle of leaf water potential (Herrero and Johnson, 1981). Shaw (1974) recommended giving moisture stress around silking more weight than stress at other stages in models to predict grain yield.

Moisture stress initiated mobilization of carbohydrate to the stalk (Maranville and Paulsen, 1970), and increased plant sugar content (Thakur and Rai, 1980). A dramatic decline in nitrate reductase activity and protein synthesis accompanied a 15% drop in leaf turgor pressure (Thakur and Rai, 1980). Detasseling and cytoplasmic male sterility improved the drought tolerance of hybrids (Grogan, 1956; Duvick, 1958; Vincent and Woolley, 1972). Free proline and asparagine were implicated in the maintenance of cell turgor and volume (Pintér et al., 1978 and 1979a). Higher soil moistures were required to maintain turgor during flowering, when nitrogen utilization is maximum (Vincent and Woolley, 1972).

Considerable differences were found among hybrids for drought tolerance as measured by grain yield (Huber et al., 1953; Termunde et al., 1963; Kilen and Andrew, 1969; Barnes and Woolley, 1969; Pintér et al., 1978; Ackerson, 1983; Sanchez et al., 1983). Characteristics associated with drought tolerance were seedling heat tolerance, stable chlorophyll, greater leaf sheath conductance, faster rate of vascular tissue development, no top firing, tall plants (Kilen and Andrew, 1969), small ear size (Termunde et al., 1963), two-eared type, timely silking, maintenance of upper leaf turgor (Barnes and Woolley, 1969), low stomatal number (Ali and Naidu, 1982), and more responsive stomatal closure and leaf rolling (Ackerson, 1983). Differences in recovery time among hybrids varied more than did the onset of stress symptoms and recovery time had more influence on grain yield (Sanchez et al., 1983). Jensen and Cavalieri (1983) showed that yield potential and drought tolerance, although negatively correlated, were not necessarily mutually exclusive. They suggested concentrating on anthesis-to-silking interval and other morphological and physiological traits in selecting for drought tolerance of grain yield. Ali and Naidu (1982) found that the correlations between grain yield and ear components were increased by moisture stress.

#### EAR COMPONENTS

Studies of ear components of yield in the Corn Belt were promoted by ear shows which began in Chicago about 1865. The standard score card for

judging and selecting ears was developed from a card used at the original show and the standard card remained popular until after 1910. The introduction of hybrid maize on a commercial level caused a radical decline in interest in ear components in the late 1930's. Breeding schemes based on yield testing were given great attention. It was not until the middle 1960's that interest in correlation studies of ear components was renewed following the controversy over planting densities, spacings, and nitrogen fertilization rates.

Studies on the grain yield response to selection of "superior" types of seed ears within open-pollinated cultivars produced largely negative results (Ewing, 1910; McCall and Wheeler, 1913; Cunningham, 1916; Williams, 1915; Grantham, 1917; Love and Wentz, 1917; Hutcheson and Wolfe, 1918; Olsen et al., 1918; Biggar, 1919). Selection for grain yield based on the combined score-card score produced no better results than selection upon a single ear trait (Olsen et al., 1918). Ear kernel row number was negatively correlated with grain yield in open-pollinated cultivars (Cunningham, 1916; Love and Wentz, 1917; Olsen et al., 1918), and kernel row number and barrenness were positively correlated. Long slender ears were thus favored in selection on ear type (Kyle and Stoneberg, 1925). Efficiency of selection was improved somewhat, first by adopting the ear-to-row method (Olsen et al., 1918; Cunningham, 1916; Hutcheson and Wolfe, 1918) and secondly by abandoning the score card method and relying on grain yield testing. Twice the response, or 0.35

megagrams(Mg) per hectare (5.6 bu/a) per cycle, was achieved using ear-to-row yield testing rather than ear-to-row ear component selection(Olsen et al., 1918). Interest shifted to inbred line development and hybrid maize production when Hayes(1926) demonstrated conclusively the superior grain yield potential of hybrids. Correlations between inbred ear components and grain yield of hybrid progeny were better than those between parent ear components and offspring yield of open-pollinated cultivars. General vigor of inbreds was found more important to hybrid grain yield than ear traits, however(Nilsson-Leissner, 1927; Jorgenson and Brewbaker, 1927; Jenkins, 1929; Hayes and Johnson, 1939). The most important factor contributing to the superiority of hybrids was their reduced frequency of barren plants(Stringfield and Thatcher, 1947).

The inheritance of ear components was largely controlled by genes with additive effect, especially in non-selected populations. Significant non-additive genetic variances were calculated for grain yield, ear length, kernel row number, ear diameter, kernel depth, cob diameter, and ears per plant. Generally, their levels suggest partially to completely dominant gene action, but over-dominance was not ruled out (Gardner et al., 1953; Robinson et al., 1955 and 1958; Rumbaugh and Lonnquist, 1959; Gardner and Lonnquist, 1959; Lindsey et al., 1962; Hallauer, 1971; Rama Murthy et al., 1981; Sanghi et al., 1982). Both positive(Robinson et al., 1958), and negative(Eberhart et al., 1966; Stuber et al., 1966) estimates of epistasis for grain yield were calculated.

Correlations based on means and additive genetic effects between grain yield and ear length, ear diameter, kernel row number, kernel depth, and kernel weight were significant in 'Reid's Yellow Dent' (Williams et al., 1965) and two synthetic cultivars (Hallauer, 1971). Selection based upon ear components was recommended (Williams et al., 1965). Heritabilities of grain yield and ear components were all above 0.50 in the Williams et al. (1965) study and were significant in the Hallauer (1971) study. Russell and Teich (1967) found that selection of inbreds on the basis of vigor, ear type, and anthesis-to-silking interval was as good as test-cross selection and produced better inbred lines per se provided that population densities were high. Heritability estimates of grain yield and a number of ear components ranged from 0.64 to 0.91 when inbred lines were evaluated. Correlations of means between grain yield and ear components ranged from 0.56 for kernel row number to 0.76 for kernel depth. The positive correlations of yield and kernel row number are in marked contrast to the negative correlations typical of open-pollinated cultivars. Gama and Hallauer (1977) observed low correlations between inbred ear components and hybrid grain yield when planting density and seasonal stresses were not great.

Both kernels per ear (Landi et al., 1983; and kernel size (Singh and Asnami, 1979) were determined to be important to yield depending on germplasm and season or location. Landi et al. (1983) believed that a balanced expression of ear components was necessary for maximum yield. Ear number

per plant was most important to grain yield in other studies(El-Lakany and Russell, 1971; Mock and Pearce, 1975; Motto and Moll, 1983; Buren et al., 1974). Ear size has been shown to be limiting in the Southern Corn Belt but not in the Northern Corn Belt(Daynard et al., 1977; Tollenaar, 1977). Anthesis-to-silking interval was negatively correlated with grain yield(Landi et al., 1983; Mock and Pearce, 1975; El-Lakany and Russell, 1971; Buren et al., 1974; Edmeades et al., 1979b).

Johnson and Tanner(1972) identified three stages of post silking ear development: 1) a lag period of 15 to 18 days before rapid dry matter accumulation, 2) a period of rapid linear dry matter accumulation, and 3) a period of declining rate of dry matter accumulation ending in black layer formation. The lag period has been implicated as the period of endosperm mitosis(Crane, 1964; Michael and Seiler-Kelbitch, 1972; Hanway and Russell, 1969), and endosperm cell number determines potential kernel volume(Wardlow, 1970; Fischer and Wilson, 1975; Claassen and Shaw, 1970a; Wilson and Allison, 1978; Tollenaar and Daynard, 1978). Endosperm cell number was found to determine kernel fill rate(Jones and Simmons, 1983; Cross, 1975). Differences among hybrids for grain yield were due to differences in duration of grain fill(Daynard et al., 1971), and rate of grain fill(Carter and Poneleit, 1973). Higher planting density reduced the rate of grain fill(Daynard et al., 1971). Both duration of grain fill, which is related to maturity(Cross, 1975; Daynard and Kannenberg,

1976), and rate of fill(Ottaviano and Camussi, 1981) were shown to influence grain yield.

Remobilization of soluble carbohydrates from the stalk to the ear was found to be dependent on temperature and to be independent of current photosynthesis rates(Duncan et al., 1965). The stalk has been shown to be an important reservoir for soluble carbohydrates(Daynard et al., 1969; Hume and Campbell, 1962; Barnett and Pearce, 1983). Stalk strength and stalk rot resistance were negatively correlated with grain yield and ear components(Devey and Russell, 1983).

Stepwise multiple regression analysis, factor analysis, and path coefficient analysis have been useful supplements to simple correlations in determining underlying causalities and confounding effects in the relationship between ear components and grain yield. Kernel row number was found more important in earlier varieties. A portion of the effect of kernel row number had negative influence on grain yield by reducing grain filling rate and kernels per row(Ottaviano et al., 1975; Fakorede, 1979; Ottaviano and Camussi, 1981; Pè et al., 1982; Pè and Camussi, 1982).

#### COMBINING ABILITY

Sprague and Tatum(1942) introduced the concept of general and specific combining ability as properties of individuals within a population. Gen-

eral combining ability(GCA) was defined as the average performance of a parent in combination with all other parents in the population. Specific, or special combining ability(SCA) was defined as the deviation from the expected performance of a cross based on the average performance of its parents. The expected performance is the average of the two GCA's of the parents. Rojas and Sprague(1952) studied variance components for grain yield in two groups of single crosses and found that the SCA variance component included not only dominance and epistatic variance, but also a substantial portion of additive-genetic- by-environment interaction. GCA variance components decreased when data were combined over locations and years(Matzinger et al., 1959), suggesting a strong influence of SCA effects in producing stable grain yield over environments. These findings were confirmed by Hallauer(1971) who found that considerable additive genetic variance was lost to the non-additive component when grain yield data from two Iowa synthetic cultivars were combined over locations and years. However, Williams et al.(1965) found that dominance-to-additive variance ratios for grain yield declined when data from 'Reid's Yellow Dent' were combined over seasons.



## MATERIALS AND METHODS

Twelve inbred lines of maize were selected as representative of Corn Belt germplasm, based primarily on their yield potential in hybrid combination. The lines were Va.79:419, A619, A632, B73, H93, Mo17, Va17, H60, Pa91, H96, Oh7B, and Va85. All lines are single-eared (non-prolific) types, so confounding effects of ear components with ear number was minimized. All inbreds except Va.79:419 have been used in commercial hybrid production. The source and origin of the twelve inbred lines are listed in Table 1(Henderson, 1980). The inbreds were crossed in all possible combinations producing 66 hybrids. For all but a few crosses, equal amounts of reciprocal  $F_1$  seed was mixed to eliminate possible maternal parent effects.

The 66 hybrids were planted with hand-jab planters at Holland, Virginia on 10 April 1981, and 15 and 16 April 1982 in a split-plot design with hybrids in whole plots and planting density treatments in sub-plots arranged in strips perpendicular to the whole plots. There were three replications per year and density treatment strips and hybrids were randomized within each replication. The soil types were a coarse, loamy, siliceous, thermic aquic hapludult in 1981 and a loamy, siliceous, thermic arenic paleudult in 1982. Fertilization in 1981 consisted of 448 kg/ha

Table 1. Pedigree, origin, and release year of the twelve inbred lines used in the diallel cross.

Inbred line	Pedigree	Origin	Release year
A619	(A171 X Oh43) Oh43	Minnesota	1961
A632	(Mt42 X B14) B14 <sup>3</sup>	Minnesota	1964
B73	Iowa Stiff Stalk Synthetic recurrent sel. pop. C5	Iowa	1972
H60	(Mo21A X CI.14) X (Oh28 X Oh51A)	Indiana	1959
H93	(B37 X GE440) X B37 <sup>4</sup> <sub>HtHt</sub>	Indiana	1966
H96	(H55 X H56)	Indiana	1968
Mo17	(187-2 X C103)	Missouri	1964
Oh7B	(Oh07 X 38-11) Oh07	Ohio	1956
Pa91	(Wf9 X Oh40B)S <sub>4</sub> X (38-11 X L317)38-11 S <sub>4</sub>	Pennsylvania	1971
Va17	Wf9 X T8	Virginia	1961
Va.79:419	Indiana Southern Synthetic A	Virginia	Unreleased
Va85	Virginia Long Ear Synthetic	Virginia	1975

of 6-12-36 applied before planting and 72.8 kg/ha of actual nitrogen applied as a liquid at planting. These rates in 1982 were 392 kg/ha and 72.8 kg/ha, respectively. An additional 72.8 kg/ha of nitrogen was applied as a liquid side-dressing at thinning in both years, and 34.7 kg/ha of supplemental nitrogen was applied on 17 June 1982 to compensate for heavy rainfall after thinning.

Two seeds were planted per hill and hills were thinned to one plant per hill on 21 May 1981 and 2 June 1982. Chains, space-marked with poultry leg rings, were utilized at planting to assure even spacing of seeds. Sections of the planting chain, corresponding to different population densities, were made interchangeable to facilitate randomization of density treatments within replications. Sub-plots were planted with 13 hills, with one double planted hill between each sub-plot to mark changes in planting density treatments. Rows were approximately 91 cm (36 inches) apart and leg rings were spaced on the chain to produce populations of 39,536 pl/ha (16,000 pl/a), 49,420 pl/ha (20,000 pl/a), 59,304 pl/ha (24,000 pl/a), and 69,188 pl/ha (28,000 pl/a). The three end hills of each whole-plot were double planted at high density to reduce end of row effect.

Data were recorded from five competitive plants in the center portion of each sub-plot where possible. Atypical portions of sub-plots were avoided in data taking. Plants from which data were taken were tagged just prior

to pollen shed. The dates of first pollen shed, first silk emergence, and last pollen shed, as measured from the date of planting, were recorded on an individual plant basis on the tag of the respective plant. The date of first anther extrusion for an individual plant was considered the first day of pollen shed, even though only one or two florets may have extruded anthers. The last day of pollen shed was determined by back-dating one day from the first day when no fresh anthers were extruded from the tassel. Fresh anthers are greenish or purplish and move easily in the breeze. Day-old anthers are straw brown and are generally stuck to the tassel and to other anthers. Date of silk emergence was determined as the first day when a few or more silks emerged from the end of the top ear shoot. If only a few silks were observed emerging during an afternoon data taking session, the silking date was up-dated to the next day, since little pollen would be available for pollination in the afternoon. In general the number of silks emerging on the first day was large, rarely being just a few.

The ear from each tagged plant was hand harvested on 9-11 September 1981 and 2 and 3 September 1982. Tags from individual plants were rubber-banded to their respective ears. In the event of a barren plant, another ear from the same sub-plot was substituted and the substitution was noted on the tag. Ear length, ear diameter, cob diameter, kernel row number, kernels per row, and grain weight adjusted to 15.5% moisture were recorded for each ear. Ear length, from the butt to the end of grain fill, was

measured to the nearest centimeter with a ruler. Ear diameter and cob diameter at the center of the length of the ear were measured to the nearest millimeter with calipers. Ear kernel row number was counted at the center of the length of the ear. Kernels per row on the ear was counted for one typical row of kernels on each ear. Grain moisture percentage was measured with a John Deere and Company moisture meter, Model TY9304.

The characters which were analyzed statistically (Table 2) were days from planting to first pollen shed, anthesis-to-silking interval (silking delay), duration of pollen shed (pollen-shed interval), duration of pollen shed after silk emergence, ear length, kernels per row on the ear, ear kernel row number, ear kernel number (kernel row number times kernels per row), kernel width at mid-kernel depth, kernel depth (length or distance from point of attachment to cob to the dent of the kernel), kernel thickness (ear length divided by kernels per row), grain yield, and grain yield adjusted to remove the effects of barrenness (random ear from the same sub-plot substituted for aborted ear). Exact definitions of each trait analyzed are listed in Table 2. The statistical procedures used are described in the Statistical Procedures section.

**Table 2. List of characters measured, and their trait codes and definitions from a twelve-parent diallel study of maize.**

Character	Trait code	Definition
Days to pollen shed	DPS	Number of days from planting to first pollen shed
Days of silking delay	DSD	Number of days from planting to first silk minus DPS
Pollen-shed interval	PSI	Number of days from planting to last pollen shed minus DPS
Days of pollen shed after silk emergence	ASE	PSI - DSD
Ear length	EL	Ear length in centimeters
Kernels per row	KPR	Number of kernels on a typical row of kernels on the ear
Ear kernel number	KN	KPR x KRN
Kernel row number	KRN	Number of rows of kernels on the ear
Kernel width	KW	(KD + Cob diameter) / KRN, in millimeters
Kernel depth	KD	(Ear diameter - cob diameter) / 2, in millimeters
Kernel thickness	KTH	EL / KPR, in millimeters
Grain yield	Y	Yield of grain at 15.5% moisture in megagrams per hectare
Grain yield per plant	PY	Yield of grain in grams per plant at 15.5% moisture
Grain yield adjusted to remove the effects of barrenness	AY	Yield of grain with random ears substituted for barren plants
Grain yield per plant adjusted to remove the effects of barrenness	PAY	Yield of grain per plant with random ears substituted for barren plants

## STATISTICAL PROCEDURES

These data were analyzed as a replicated split-plot design with hybrids as whole plots and planting density treatments in strips across the whole plots. The linear model for all traits is:

$$Y_{ijkm} = \mu + \alpha_m + \beta_{ij} + \varepsilon_{ijm}^1 + \gamma_k + \varepsilon_{km}^2 + (\beta\gamma)_{ijk} + \varepsilon_{ijkm}^3$$

where

$Y_{ijkm}$  = the mean of the observations for the  $i^{\text{th}}$   
 $X_j^{\text{th}}$  cross,  $i \neq j = 1, 2, 3, \dots, 12$  in  
density  $k$ , in replication  $m$

$\mu$  = the population mean

$\alpha_m$  = the effect of the  $m^{\text{th}}$  replication,  $m = 1, 2, 3$

$\beta_{ij}$  = the effect of the  $(i \times j)^{\text{th}}$  hybrid;  $i, j =$   
 $1, 2; 1, 3; \dots; 11, 12; i < j$

$\varepsilon_{ijm}^1$  = residual error (1)

$\gamma_k$  = the effect of the  $k^{\text{th}}$  density,  $k = 1, 2, 3, 4$

$\varepsilon_{mk}^2$  = residual error (2)

$(\beta\gamma)_{ijk}$  = the interaction of the  $(i \times j)^{\text{th}}$   
hybrid with the  $k^{\text{th}}$  density

$\varepsilon_{ijkm}^3$  = residual error (3)

Analysis of variance was performed on the mean of the five observations within each replication-density combination using the ANOVA procedure of SAS (SAS User's Guide, 1979). Statistical significance was determined by F-test using the appropriate error terms based on expected mean squares. The expected mean squares for the analysis of variance within each year combined over the four planting densities are presented in Table 3. Table 4 shows the expected mean squares for the analysis combined over both years. Tables 5 and 6 give expected mean squares for the separate analysis within densities across years and within years, respectively.

The data for three plots, missing in 1981, were estimated so as to facilitate computer analysis. The estimation technique used was multiple analysis of covariance (Coons, 1957) as adapted by Hinkelmann (1968) to diallel experiments. Missing values were obtained separately for each replication-density combination.

The following is an example to illustrate the procedure:

Suppose there were two missing plots each for different hybrids of different parents;  $p \times q$ , and  $r \times s$ . From the analysis of covariance using Hinkelmann's notation,



Table 3. Expected mean squares of flowering traits and ear components of yield combined over four planting densities within one year from a twelve-parent diallel of maize.

Source of variation	df	Expected mean squares	
		Model I	Model II
Rep	2		
Hybrids	65	$\sigma_3^2 + 4\sigma_1^2 + 12\phi_H$	$\sigma_3^2 + 4\sigma_1^2 + 12\sigma_H^2$
GCA	11	$\sigma_3^2 + 4\sigma_1^2 + \frac{120}{11}\phi_{GCA}$	$\sigma_3^2 + 4\sigma_1^2 + 12\sigma_{SCA}^2 + 120\sigma_{GCA}^2$
SCA	54	$\sigma_3^2 + 4\sigma_1^2 + \frac{24}{108}\phi_{SCA}$	$\sigma_3^2 + 4\sigma_1^2 + 12\sigma_{SCA}^2$
Error (1)	130	$\sigma_3^2 + 4\sigma_1^2$	$\sigma_3^2 + 4\sigma_1^2$
Density	3	$\sigma_3^2 + 66\sigma_2^2 + 198\phi_D$	$\sigma_3^2 + 66\sigma_2^2 + 198\sigma_D^2$
Error (2)	6	$\sigma_3^2 + 66\sigma_2^2$	$\sigma_3^2 + 66\sigma_2^2$
Hybrid x Density	195	$\sigma_3^2 + 3\phi_{HxD}$	$\sigma_3^2 + 3\sigma_{HxD}^2$
Error (3)	390	$\sigma_3^2$	$\sigma_3^2$

Table 4. Expected mean squares of flowering traits and ear components of yield combined over four planting densities and two years from a twelve-parent diallel of maize.

Source of variation	df	Expected mean squares	
		Model I	Model II
Years	1		
Rep(Year)	4		
Hybrids	65	$\sigma_3^2 + 4\sigma_1^2 + 24\phi_H$	$\sigma_3^2 + 4\sigma_1^2 + 24\sigma_H^2$
GCA	11	$\sigma_3^2 + 4\sigma_1^2 + \frac{240}{11}\phi_{GCA}$	$\sigma_3^2 + 4\sigma_1^2 + 24\sigma_{SCA}^2 + 240\sigma_{GCA}^2$
SCA	54	$\sigma_3^2 + 4\sigma_1^2 + \frac{48}{108}\phi_{SCA}$	$\sigma_3^2 + 4\sigma_1^2 + 24\sigma_{SCA}^2$
Hybrid x Year	65	$\sigma_3^2 + 4\sigma_1^2 + 12\phi_{HxY}$	$\sigma_3^2 + 4\sigma_1^2 + 12\sigma_{HxY}^2$
Error (1)	260	$\sigma_3^2 + 4\sigma_1^2$	$\sigma_3^2 + 4\sigma_1^2$
Density	3	$\sigma_3^2 + 66\sigma_2^2 + 396\phi_D$	$\sigma_3^2 + 66\sigma_2^2 + 396\sigma_D^2$
Density x Year	3	$\sigma_3^2 + 66\sigma_2^2 + 198\phi_{DxY}$	$\sigma_3^2 + 66\sigma_2^2 + 198\sigma_{DxY}^2$
Error (2)	12	$\sigma_3^2 + 66\sigma_2^2$	$\sigma_3^2 + 66\sigma_2^2$
Hybrid x Density	195	$\sigma_3^2 + 6\phi_{HxD}$	$\sigma_3^2 + 6\sigma_{HxD}^2$
Hybrid x Density x Year	195	$\sigma_3^2 + 3\phi_{HxDxY}$	$\sigma_3^2 + 3\sigma_{HxDxY}^2$
Error (3)	780	$\sigma_3^2$	$\sigma_3^2$

Table 5. Expected mean squares of flowering traits and ear components of yield within one planting density and combined over two years from a twelve-parent diallel of maize.

Source of variation	df	Expected mean squares	
		Model I	Model II
Years	1		
Rep(Year)	4		
Hybrids	65	$\sigma_3^2 + 6\phi_H$	$\sigma_3^2 + 6\sigma_H^2$
GCA	11	$\sigma_3^2 + \frac{60}{11}\phi_{GCA}$	$\sigma_3^2 + 6\sigma_{SCA}^2 + 60\sigma_{GCA}^2$
SCA	54	$\sigma_3^2 + \frac{12}{108}\phi_{SCA}$	$\sigma_3^2 + 6\sigma_{SCA}^2$
Hybrid x Year	65	$\sigma_3^2 + 3\phi_{HxY}$	$\sigma_3^2 + 3\sigma_{HxY}^2$
Error	260	$\sigma^2$	$\sigma^2$

Table 6. Expected mean squares of flowering traits and ear components of yield within one planting density and one year from a twelve-parent diallel of maize.

Source of variation	df	Expected mean squares	
		Model I	Model II
Rep	2		
Hybrids	65	$\sigma^2 + 3\phi_H$	$\sigma^2 + 3\sigma_H^2$
GCA	11	$\sigma^2 + \frac{30}{11}\phi_{GCA}$	$\sigma^2 + 3\sigma_{SCA}^2 + 30\sigma_{GCA}^2$
SCA	54	$\sigma^2 + \frac{6}{108}\phi_{SCA}$	$\sigma^2 + 3\sigma_{SCA}^2$
Error	130	$\sigma^2$	$\sigma^2$

$$E_{xz} = 2/[(n-1)(n-2)] = 0.0182 \text{ and,}$$

$$E_{xx} = 1-2/(n-1) = 0.8182,$$

where  $n$  = the number of parents in the experiment.

The estimates are found by solving the system of equations:

$$\begin{vmatrix} 0.8182 & 0.0182 \\ 0.0182 & 0.8182 \end{vmatrix} \begin{vmatrix} \hat{Y}_{pq} \\ \hat{Y}_{rs} \end{vmatrix} = \begin{vmatrix} 0.1(Y_p + Y_q) - 0.009Y. \\ 0.1(Y_r + Y_s) - 0.009Y. \end{vmatrix}$$

where  $Y_p$  = the total of all observations for hybrids of parent  $p$  in the missing replication-density combination

$Y.$  = twice the grand total of all observations in the missing replication-density combination

Then,

$$\begin{vmatrix} \hat{Y}_{pq} \\ \hat{Y}_{rs} \end{vmatrix} = \begin{vmatrix} 0.8182 & 0.0182 \\ 0.0182 & 0.8182 \end{vmatrix}^{-1} \begin{vmatrix} 0.1(Y_p + Y_q) - 0.009Y. \\ 0.1(Y_r + Y_s) - 0.009Y. \end{vmatrix}$$

are the estimates of the missing values.

The error degrees of freedom in the analysis of variance should be reduced by the number of estimated values. Adjustments were not made in this study because they did not substantially change the outcome of the tests for significance.

Combining ability analyses were performed on the means of each  $F_1$  cross for all flowering and ear traits analyzed previously by ANOVA. Model I of Eisenhart(1947), which assumes that all factors in the experiment except error are fixed, was used for the analysis(since the parents were not a sample from a random mating population) with Method 4 of Griffing (1956), a procedure for analyzing diallels of  $F_1$ s only, with no parents or reciprocals included. The computer program used in the combining ability analysis was that of Schaffer and Usanis(1968).

The model for this combining ability analysis is given by Griffing as:

$$Y_{ij} = \mu + g_i + s_{ij} + e_{ijkm}$$

$$i \neq j, ij = 1,2;1,3;\dots 11,12$$

$$k = 1,2,3$$

$$n = 1,2,3,4$$

where  $\mu$  is the population mean,  $g_i$  and  $g_j$  are the general combining ability effects for lines  $i$  and  $j$ ,  $s_{ij}$  is the specific combining ability effect for hybrid  $i \times j$ , and  $\varepsilon_{ijklm}$  is the error effect for the  $ijklm^{\text{th}}$  mean. Combining abilities are as defined by Sprague and Tatum(1942). That is, general combining ability is the average effect of a parent in hybrid combination and specific combining ability is the deviation that a particular cross has from the average performance of its parents. The restrictions  $\sum_i g_i = 0$  and  $\sum_{i \neq j} s_{ij} = 0$  are imposed on the combining abilities. This analysis is a least squares procedure for estimating these combining ability effects.

Specific combining ability(SCA) variances associated with each parent were calculated so as to determine how consistently a parent transmitted its average performance. The formula for these variances follows:

$$\hat{\sigma}_{s_i}^2 = \frac{1}{p-2} \sum s_{ij}^2$$

The computational formula using the calculated SCA effects is:

$$\hat{\sigma}_{s_i}^2 = \frac{1}{p-2} \sum s_{ij}^2 - \frac{p-3}{p-2} \hat{\sigma}_{RXH}^2$$

where  $\hat{\sigma}_{s_i}^2$  = the SCA variance,

$s_{ij}^2$  = the squared value of the SCA effect

$(s_{ij})$  for hybrid  $i \times j$ ,

and  $\hat{\sigma}_{RXH}^2$  = error (1) divided by 4 densities x  
3 replications. The error would be divided by  
an additional factor of 2 for the analysis  
combined over years.

Estimates of variance components for GCA and SCA were calculated based on a completely random model (Model II of Eisenhart). This was deemed useful despite the parents previously being considered fixed effects.

Narrow-sense heritability estimates (which estimate the proportion of additive genetic variance to phenotypic variance) for the characters studied were calculated from the estimates of the variance components. The formula of Hallauer and Miranda (1981, p.63) modified for the case of completely inbred parents is:

$$h^2 = \frac{2\hat{\sigma}_{GCA}^2}{\hat{\sigma}_{RXH}^2 + \hat{\sigma}_{SCA}^2 + 2\hat{\sigma}_{GCA}^2}$$



and that for standard error of the estimates is:

$$\text{S.E.}(h^2) = \frac{\text{S.E.}(2\hat{\sigma}_{\text{GCA}}^2)}{\hat{\sigma}_{\text{RXH}}^2 + \hat{\sigma}_{\text{SCA}}^2 + 2\hat{\sigma}_{\text{GCA}}^2}$$

Simple correlations were calculated between the hybrid means, GCAs, and SCAs of all characters within and across seasons and between the hybrid means, GCAs, and SCAs within densities, within and across seasons.

## RESULTS AND DISCUSSION

The daily rainfall amounts from planting to harvest at the Holland research station in 1981 are presented in Figure 1. The period during flowering was preceded by three weeks of little rainfall. On day 71 post-planting 2 mm of rain fell, but was insufficient to prevent mid-day wilting of plants during early flowering. The moisture stress was alleviated on day 85 and the average date of anthesis was day 80. Moisture levels were adequate for the remainder of the season. Moisture demand was shown to be greatest just prior to and during flowering. Moisture stress prior to silking had the greatest effect on delaying silk emergence (Hall et al., 1982). Daily high and low temperatures in 1981 are presented in Figure 2. The period just before and at the beginning of flowering had daily highs slightly below 38°C. These temperatures make the observed mid-day wilting understandable.

The average date of anthesis in 1982 was day 77 after planting. Two periods of moderate rainfall preceded flowering (Figure 3) and the daily high temperatures were 32°C or below (Figure 4). These factors, combined with low rainfall early in the season, which possibly stimulated more extensive root development, prevented wilting prior to or during flowering.

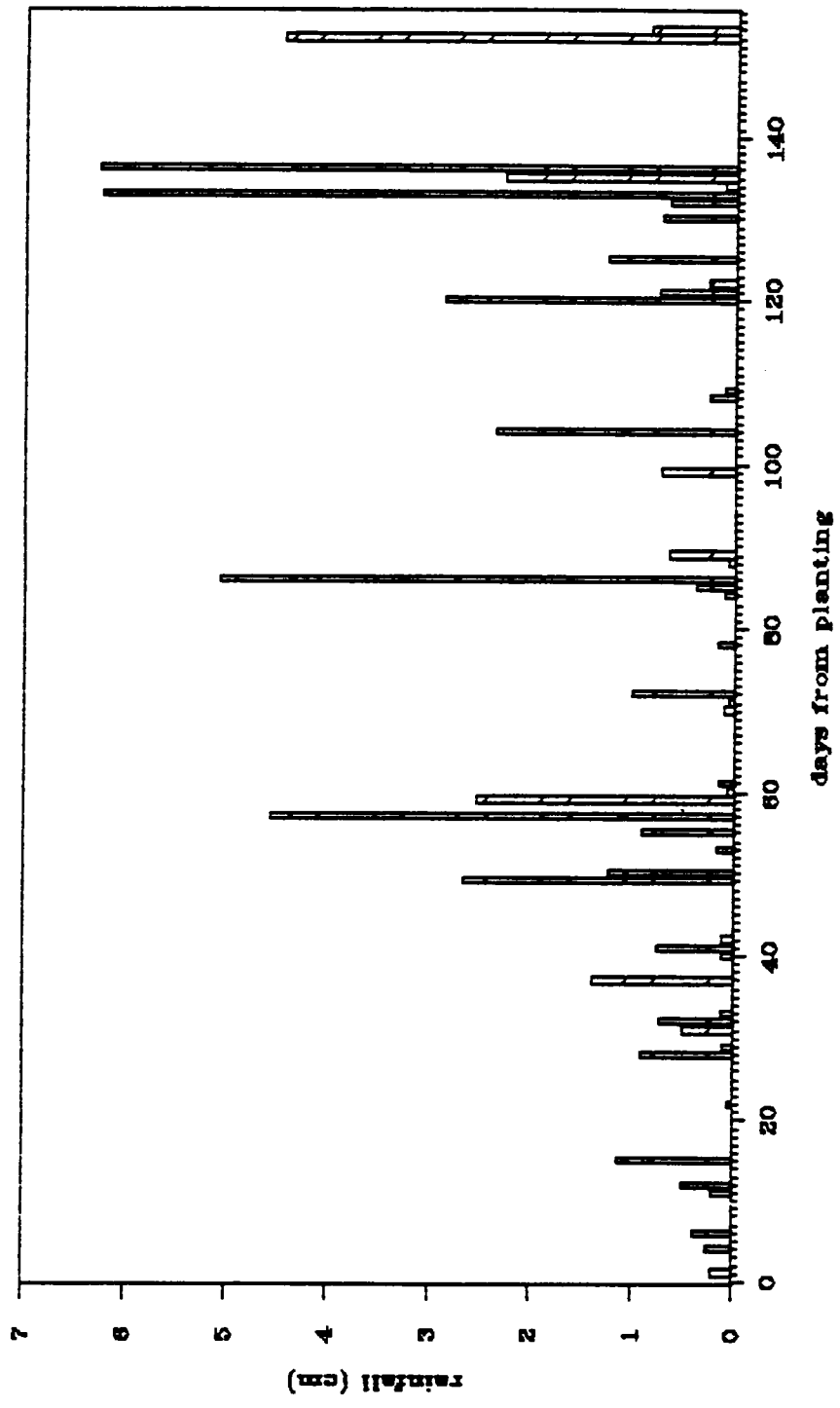


Figure 1. Daily rainfall at Holland, Virginia during the 1981 season.

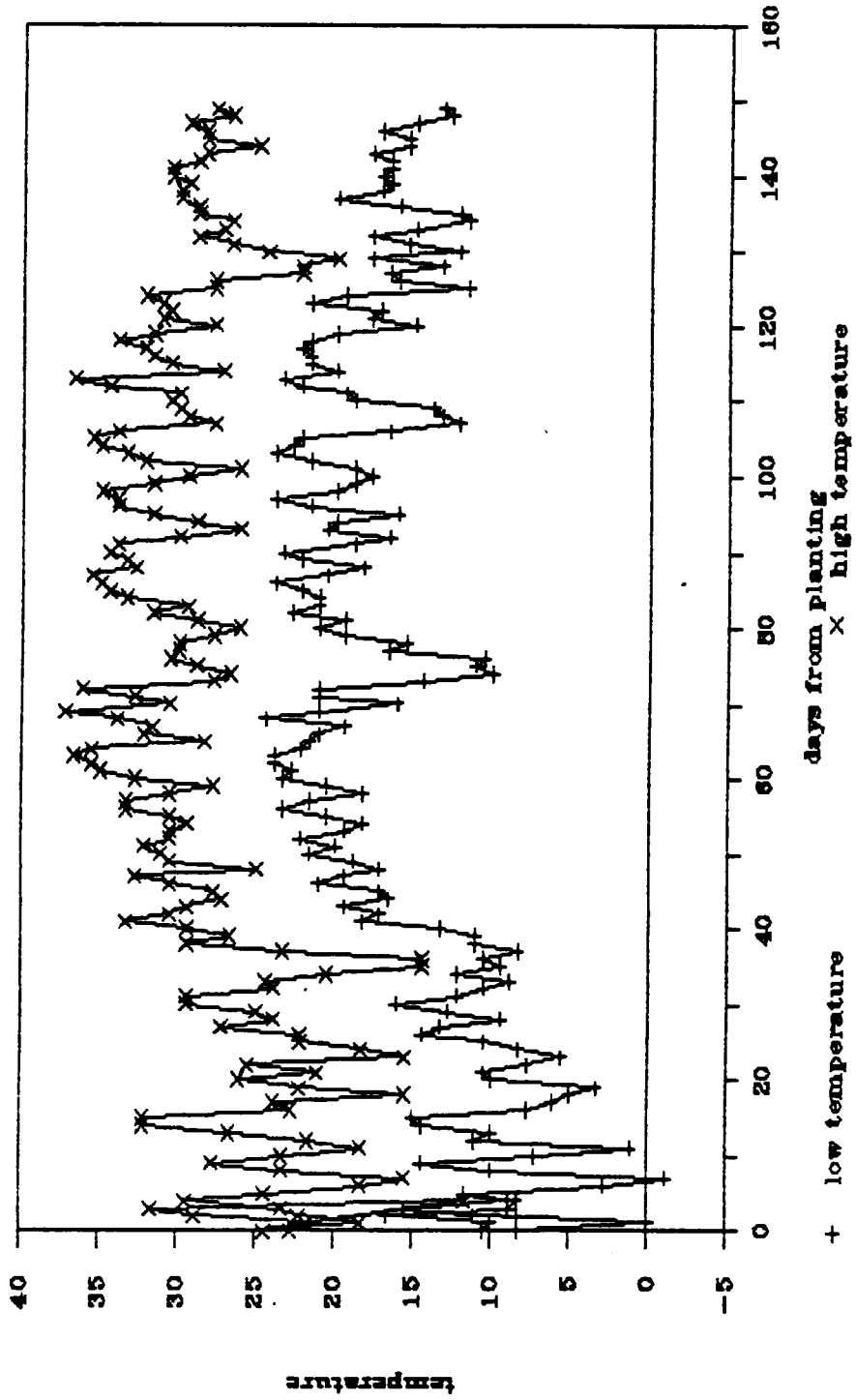


Figure 2. Daily maximum and minimum temperatures in degrees centigrade at Holland, Virginia during the 1981 season.

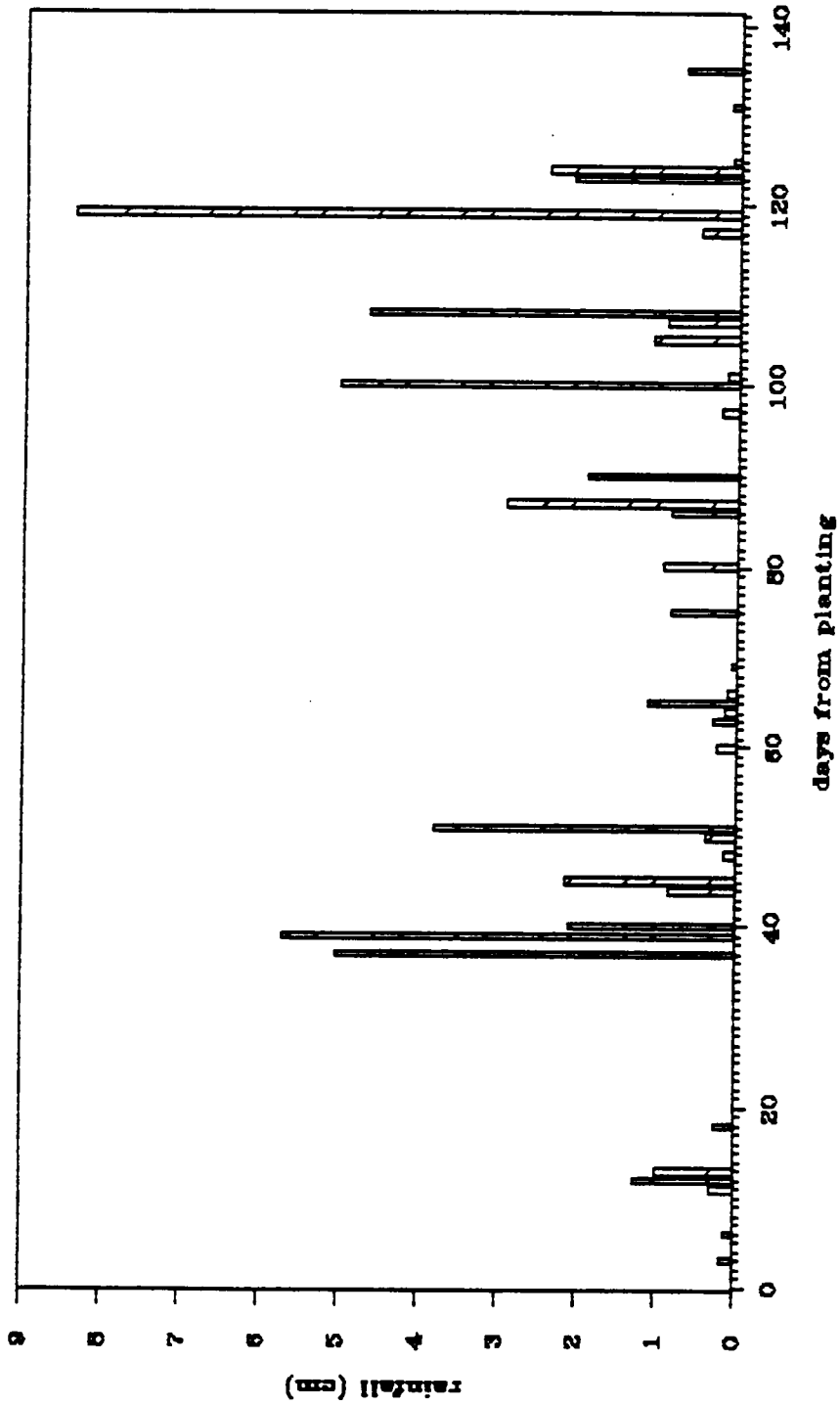


Figure 3. Daily rainfall at Holland, Virginia during the 1982 season.

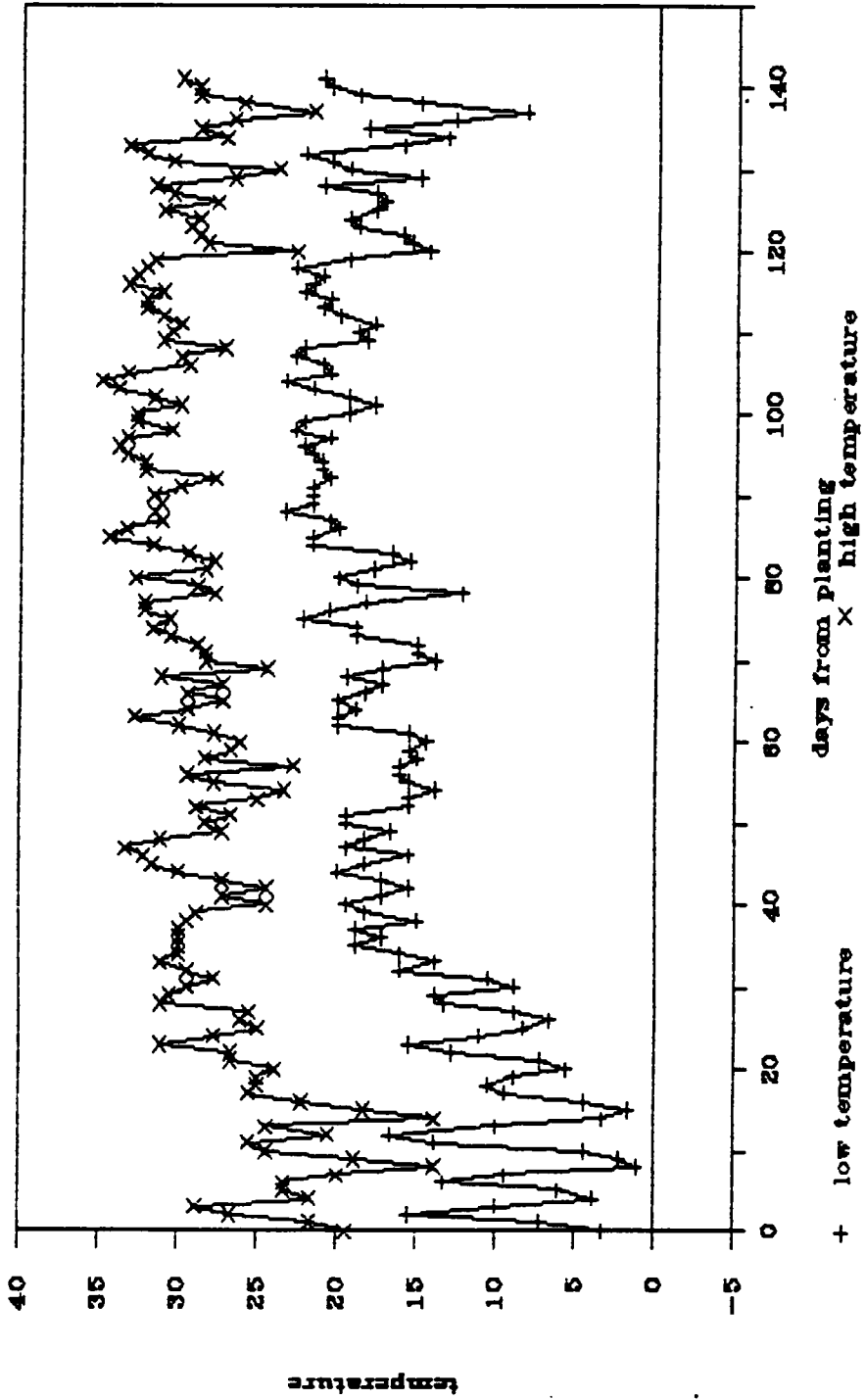


Figure 4. Daily maximum and minimum temperatures in degrees centigrade at Holland, Virginia during the 1982 season.

## EFFECTS OF POPULATION DENSITY

The analyses of variance for flowering traits and ear components of yield in 1981, 1982, and combined across both years are presented in Table 7, Table 8, and Table 9, respectively. All genetic treatment effects (hybrid, GCA, and SCA) for all traits were highly significant (0.01 level of probability) except for a significant (0.05 level of probability) SCA effect for days from planting to first pollen shed (DPS) in 1982. The discussion of hybrid treatments, therefore will be deferred until after a discussion of population density effects.

Although the effect of population density on DPS was significant in 1981 (Table 7) and highly significant in 1982 (Table 8), the actual change in time of anthesis resulting from population density (1 day) was erratic (Table 10). The effect of season was much greater, producing a delay of almost 3 days in the 1981 mean over that of 1982. Hybrid-by-density interactions for DPS were non-significant in both years and in the combined analysis. Therefore no significant differences in hybrid response to density were apparent. The effect of population density and season on days of silking delay (DSD, or anthesis-to-silking interval) increased from 0.79 days at 39,536 pl/ha in 1982 to 5.17 days at 69,188 pl/ha in 1981 (the season with wilting prior to and during flowering). The influence of higher density in producing increased DSD is reflected in the highly significant mean squares for density in both years and in

Table 7. Analyses of variance of flowering and ear traits for 66 hybrids (12-parent diallel) grown at four population densities in 1981.

Source	d.f.	Mean squares for indicated trait <sup>a</sup>													
		DPS	DSD	PSI	ASE	EL	KPR	KN	KRN	KM	KO	KTH	Y	AY	
Rep	2	36.611	1.170	5.444	11.294	26.099	307.088	66372	1.127	5.013	6.798	0.859	12.821	15.028	
Hybrid	65	77.405**	36.508**	8.319**	29.257**	34.345**	193.483**	63843**	31.014**	4.506**	4.703**	5.084**	12.958**	11.745**	
CCA	11	416.808**	170.001**	39.463**	133.678**	150.729**	725.323**	246703**	165.735**	23.141**	16.639**	21.574**	36.261**	31.642**	
SCA	54	8.492**	9.411**	1.974**	7.986**	10.637**	85.146**	26594**	3.571**	0.710**	2.271**	1.725**	8.211**	7.691**	
Error 1	130	2.776	2.301	0.742	1.729	3.032	39.309	11702	0.573	0.217	1.174	0.818	3.818	3.640	
Density	3	41.473*	90.178**	4.403*	61.997**	500.220**	3269.898**	1024752**	11.364**	4.325**	16.990**	7.848**	38.477**	38.512**	
Error 2	6	4.455	6.376	0.894	4.325	4.601	59.762	11343	0.293	0.359	1.562	0.648	7.919	5.764	
Hybrid X Density	195	0.893	2.105**	0.497	1.662**	1.361**	9.100	3331*	0.483	0.072	0.296	0.261	1.084**	1.010**	
Error 3	390	1.167	1.168	0.497	3.934	0.897	8.602	2443	0.450	0.066	0.245	0.258	0.788	0.774	
C.V.		1.382	25.070	7.647	19.702	5.798	9.072	9.945	4.193	3.792	5.265	9.819	13.268	13.049	

<sup>a</sup> Trait codes as defined in Table 2  
 \*,\*\* Significant at the 0.05, and 0.01 probability level, respectively.



Table 8. Analyses of variance of flowering and ear traits for 66 hybrids (12-parent diallel) grown at four population densities in 1982.

Source	d. f.	Mean squares for indicated trait 3													
		DPS	DSD	PSI	ASE	EL	KPR	KN	KRN	KN	KD	KTH	Y	AY	
Rep	2	51.251	3.7%	0.030	3.692	27.004	0.952	1786	0.978	1.201	6.114	2.285	7.645	6.581	
Hybrid	65	44.515**	5.189**	4.972**	5.485**	53.314**	266.430**	69826**	29.694**	6.368**	3.818**	0.852**	18.439**	18.361**	
GCA	11	222.937**	25.903**	25.089**	24.251**	262.225**	1335.676**	268006**	162.546**	35.895**	14.201**	3.592**	76.021**	75.637**	
SCA	54	8.170*	1.210**	0.874**	1.663**	6.684**	48.862**	58165**	2.632**	0.353**	1.703**	0.294**	6.710**	6.693**	
Error 1	130	5.362	0.491	0.519	0.724	2.830	14.991	6622	1.027	0.172	0.867	0.142	2.690	2.662	
Density	3	44.307**	19.969**	0.078	20.466**	466.463**	2111.590**	771678**	19.638**	0.136	7.081**	0.063	209.815**	212.347**	
Error 2	6	2.566	0.528	0.371	1.061	3.035	8.012	4048	0.701	0.054	0.150	0.049	2.500	2.288	
Hybrid X Density	195	0.736	0.193	0.188	0.306	0.760	4.739	1989*	0.543	0.091	0.219**	0.022**	0.832*	0.808**	
Error 3	390	0.823	0.182	0.202	0.244	0.658	4.182	1517	0.470	0.077	0.145	0.016	0.657	0.600	
C. V.		1.173	37.275	6.563	9.014	4.699	5.270	6.528	4.444	3.588	3.332	2.874	7.756	7.396	

3. Trait codes as defined in Table 2.  
 \*,\*\* Significant at the 0.05, and 0.01 probability level, respectively.

Table 9. Analyses of variance of flowering and ear traits for 66 hybrids (12-parent diallel) grown at four population densities in 1981 and 1982.

Source	d.f.	Mean squares for indicated traits <sup>a</sup>													
		DPS	DSD	PSI	ASE	EL	KPR	KN	KRN	KN	KM	KD	KTH	Y	AY
Year	1	2619.037**	3970.940**	2236.163**	246.213**	339.013*	16569.600**	2517672**	128.066**	336.722**	15% .618**	199.965**	5604.050**	5508.067**	
Repl(Year)	4	44.931	2.483	2.737	7.493	26.552	154.020	34079	1.053	3.107	6.456	1.572	10.233	10.805	
Hybrid	65	111.372**	25.830**	10.807**	22.316**	74.031**	351.986**	107378**	58.570**	10.007**	6.792**	3.984**	21.950**	20.058**	
GCA	11	403.711**	122.808**	55.838**	104.917**	363.207**	1710.106**	510549**	323.729**	56.152**	28.236**	18.311**	81.421**	76.339**	
SCA	54	11.081**	6.075**	1.634**	5.490**	11.051**	348.355**	25251**	4.556**	0.610**	2.423**	1.046	9.835**	9.556**	
Hybrid X Year	65	10.748**	16.166**	2.483**	12.426**	13.628**	108.128**	26290**	2.139**	0.867**	1.729**	1.952**	9.448**	9.248**	
Error 1	260	4.069	1.396	0.631	1.226	2.931	27.150	9162	0.800	0.195	1.020	0.480	3.254	3.161	
Density	3	69.301**	96.930**	2.132	76.506**	959.119**	5272.550**	1774764**	29.577**	2.515**	22.790**	3.393**	165.500**	175.284**	
Density X Year	3	16.479*	13.217*	2.348*	5.957	7.564	99.939	21686	1.405	1.949**	1.282	4.317**	82.792**	75.575**	
Error 2	12	3.510	3.452	0.633	2.693	5.818	33.887	7496	0.497	0.207	0.856	0.348	5.210	4.026	
Hybrid X Density	195	0.796	1.201**	0.371	1.183**	1.137**	7.041	3038**	0.563*	0.083	0.283**	0.138	1.019**	0.961**	
Hybrid X Density X Year	195	0.833	1.096**	0.314	0.766**	0.984*	6.799	2281	0.463	0.080	0.231	0.145	0.898*	0.877*	
Error 3	780	0.995	0.675	0.349	0.599	0.777	6.392	2080	0.460	0.071	0.195	0.137	0.723	0.687	
C.V.		1.269	30.120	7.360	14.598	5.249	7.108	8.191	4.316	3.686	4.241	7.489	9.918	9.629	

<sup>a</sup> Trait codes as defined in Table 2.

\*\* Significant at the 0.05, and 0.01 probability level, respectively.

Table 10. Flowering and ear traits of 66 hybrids, averaged over genotypes, grown at four population densities in 1981 and 1982.

Year	Planting density (pl/ha)	Means for indicated trait <sup>a</sup>															
		DPS	DSD	PSI	ASE	EL	KPR	KRN	KM	KD	KTH	KN	Y	AY	PY	PAY	
1981	69188	80.3	5.17	9.35	4.18	14.3	27.2	15.7	6.59	9.0	5.45	426	6.4	6.6	93	95	
	59304	79.8	4.52	9.32	4.81	16.1	31.7	16.0	6.78	9.3	5.18	505	7.3	7.3	123	124	
	49420	80.2	3.89	9.03	5.14	16.7	33.6	16.1	6.85	9.6	5.05	539	6.7	6.8	136	137	
	39536	79.3	3.67	9.17	5.50	18.2	36.9	16.2	6.94	9.7	5.01	598	6.3	6.3	159	159	
1982	69188	77.8	1.54	6.86	5.32	15.5	35.1	15.1	7.70	11.2	4.45	526	11.4	11.5	165	166	
	59304	77.6	1.23	6.82	5.58	16.6	37.4	15.3	7.71	11.3	4.46	571	11.0	11.0	186	186	
	49420	77.0	1.02	6.84	5.83	17.8	40.1	15.5	7.75	11.5	4.46	617	10.3	10.3	207	207	
	39536	76.8	0.79	6.86	6.07	19.1	42.6	15.8	7.70	11.6	4.49	672	9.1	9.1	230	231	

<sup>a</sup> trait codes as defined in Table 2.

the combined analysis. The highly significant hybrid-by-density interaction in 1981 indicated that genotypes differed in their response to density under the conditions of that season. The interaction in the 1982 analysis was far from statistical significance. The effect of density on pollen-shed interval (PSI) was statistically significant in 1981, however, there was little actual change in shed duration (Table 10). The effect of density was non-significant in 1982 and in the combined analysis. Hybrid-by-density interactions for PSI were all non-significant, thus genetic differences in response to density were not detected. The 1981 season produced a 3.5 day increase in PSI over that of the 1982 season. The hybrid-by-year interaction was highly significant for PSI, as it was for all flowering and ear traits, indicating that genotypes responded differently to seasons. The influence of density on average duration of pollen shed after silk emergence (ASE) was highly significant in the analyses for both years and in the analysis combined over years. The average ASE across all hybrids within each density-year combination ranged from 4.18 days at 69,188 pl/ha in 1981 to 6.07 days at 39,536 pl/ha in 1982. Hybrid-by-density interaction was highly significant in 1981 and in the combined analysis, but non-significant in 1982.

The effect of density on DPS, although statistically significant, was not great enough to be of biological significance. The 3 day delay of flowering in 1981 was probably due to preflowering wilting. The dramatic increase in DSD going from the lowest population density in 1982 to the

highest density in 1981 parallels the pattern of kernels per row(KPR) but in an opposite direction. This pattern confirms the commonly held belief that high DSD results in reduced yield. Of considerable interest is the highly significant hybrid-by-density interaction in 1981 and its complete absence in 1982. Apparently moisture stress has a great influence in exposing genetic differences in density tolerance with respect to DSD. Stress induced genotype-by-density interaction of silking delay has not been investigated previously. The greatly increased PSI in 1981 compared with 1982 was consistent with the findings of Hall et al.(1982). It is uncertain whether this increased duration of pollen shed was due to deleterious effects of wilting on tassel development or whether the maize plants were actively compensating for retarded development of the female inflorescence by making pollen available for a longer period. Increasing population density and increasing moisture stress prior to and during flowering reduced the time that pollen was available to emerging silks. The hybrid-by-density interaction of ASE followed the pattern of DSD, suggesting that genetic differences in pollen availability under moisture stress are largely a function of timely silking. The data on ASE alone do not indicate whether pollen availability is a factor in seed set, although other investigators suggest that floret abortion is a more important factor(Baenziger and Glover, 1980;Hall et al.,1981).

Average ear length(EL) decreased with increasing planting density(Table 10). The decrease in EL of 4.4 cm from 39,536 pl/ha to 69,188 pl/ha in

1982 was slightly greater than the decrease of 4.1 cm in 1981. Mean EL was 16.3 cm in 1981 and 17.3 cm in 1982. The hybrid-by-density interaction was highly significant in 1981 (Table 7) and in the analysis combined over years (Table 9), but was non-significant in 1982 (Table 8). The effect of density on ear EL was consistent across genotypes in 1982, and genotypes responded differently to density in 1981. The analyses of variance show a highly significant effect of planting density on average KPR on the ear in both seasons and combined over years. Average KPR increased from 27.2 kernels at 69,188 pl/ha in 1981 to 42.6 kernels at 39,536 pl/ha in 1982. Mean KPR was 32.3 in 1981 and 38.8 in 1982. There was no significant hybrid-by-density interactions for KPR in any of the analyses. Hybrids did not differ significantly in their response to density and genetic differences in KPR were expressed uniformly across densities. Ear kernel number (KN) ranged from 426 at 69,188 pl/ha to 598 at 39,536 pl/ha in 1981 and ranged from 526 at 69,188 pl/ha to 672 at 39,536 pl/ha in 1982. Ear kernel number had significant hybrid-by-density interactions in both years and a highly significant interaction in the combined analysis. The effect of density on ear kernel row number (KRN) was highly significant in both years and in the analysis combined over years. Hybrid-by-density interactions were non-significant within years, but significant in the combined analysis. Slight genetic variation in response to density is suggested. Averaged within densities, KRN ranged from 15.1 to 16.2 across both years. Average KRN was 0.5 rows greater in 1981 than in 1982.

The similarity of response to density by EL in both years was unexpected. The lower average KRN and its higher range of density averages in 1982, no doubt contributed to the high range of EL in that year. The 1 cm difference in EL between years was small compared with the 20% increase in KPR from 1981 to 1982. Kernels were more tightly packed on the row in 1982. The hybrid-by-density interactions for EL followed the same pattern as DSD and ASE, being highly significant in the season with moisture stress. The hybrid-by-density interaction was non-significant in 1982, suggesting that the 1981 interaction was moisture-stress induced. Increasing density and the occurrence of wilting during flowering resulted in a consistent decrease in KPR. This pattern suggests a connection between short DSD and high KPR. The lack of significant hybrid-by-density interactions for KPR suggests that planting at high densities would not improve selection efficiency based upon KPR. The highly significant hybrid-by-year interactions for all traits indicate that hybrids should be evaluated over many seasons. High population density is not an adequate substitute for multiple-year data. The effect of population density on KN was similar to that on KPR. Increasing population density and moisture stress resulted in reduced seed set per plant. The significant hybrid-by-density interactions for KN were unexpected, considering the non-significant interactions of both KPR and KRN. Genetic differences for kernel set in response to density are apparently a function of some underlying mechanism which adjusts total seed set per ear rather than KPR or KRN independently of each other. Seasonal stress and increased popu-

lation density produced a small but consistent reduction in KRN. The small effects of plant environment on KRN suggests that it would be a useful trait to select upon for grain yield(Y).

There was a highly significant effect of density on kernel width(KW) in 1981(Table 7) and in the combined analysis(Table 9). The effect of density was non-significant in 1982(Table 8). Hybrid-by-density interactions were non-significant in all three analyses. Mean KW(Table 10) narrowed slightly from 6.9 mm at 39,536 pl/ha to 6.6 mm at 69,188 pl/ha in 1981. The effect of density on kernel depth(KD) was highly significant in both years and combined over years. Kernel depth ranged from 9.0 mm at 69,188 pl/ha in 1981 to 11.6 mm at 39,536 pl/ha in 1982. Kernel depth decreased consistently within years with increasing density, decreasing 0.3 mm per 10,000 additional plants per hectare in 1981 and 0.1 mm in 1982. Hybrid-by-density interactions were non-significant in 1981, but were highly significant in 1982 and in the combined analysis. The effect of planting density on kernel thickness(KTH) was highly significant in the 1981 and the combined analyses. The effect was non-significant in 1982; however, hybrid-by-density interaction was highly significant. Significant effects of density in 1982, therefore, would be found for certain hybrids. For some of these hybrids KTH would increase with increasing density and for others thickness would decrease. Hybrid-by-density interactions for KTH were non-significant in 1981 and in the combined analysis. No significant differences among hybrids in the re-



sponse of KTH to density were found in these two analyses. Mean KTH ranged from 5.45 mm at 69,188 pl/ha to 5.01 mm at 39,536 pl/ha in 1981. Thicknesses were substantially lower in 1982 with a mean value of 4.47 mm.

Kernel width, by definition (Table 2), is related inversely to KRN. Yet, both KW and KRN increased with decreasing planting density in 1981. Kernel width, however, is directly dependent on KD, which also increased with decreasing density in 1981. The importance of KW in any selection scheme for Y is questionable, considering its erratic expression. If the genetic correlations between KW and Y were high, KW would be useful in selecting for Y regardless of the population density treatment. As we will see later, these correlations are generally non-significant. Further studies of KW are not recommended. Kernel depth is the only dimension of kernel size that is not restricted by ear structure, since kernels are free to expand outward. It is, therefore, expected that KD will be an important indicator of kernel volume if kernel spacing within the kernel row and KRN are constant. Also, if we imagine that corn kernels were not arranged cylindrically about the cob, but were peeled from the ear with their order intact and laid flat, the smallest dimension of the resulting rectanguloid would be kernel depth. The volume of a rectanguloid is increased most by increases in its smallest dimension. Therefore, changes in KD should have the greatest effect on grain volume of any ear dimension. The greater KTH in 1981 can be attributed to gaps

in seed set within the kernel rows, presumably caused by wilting during silking (Robins and Domingo, 1953). The missing kernels reduced compression within the kernel rows. Kernel thickness apparently has consistent value in selecting for Y only when silking is accompanied by moisture stress. Unless KTH is correlated with Y, studies of it are of no value. As will be shown later, there is a highly significant negative correlation between GCA effects of KTH and those of Y in 1981. Increasing the planting density to 69,188 pl/ha was found ineffective in improving the recognition of genetic differences in KTH.

The effect of density on Y was significant in 1981 and highly significant in 1982 and in the combined analysis. Hybrid-by-density interactions were highly significant in 1982 and in the combined analysis, and were significant in 1981. Mean Y increased throughout the range of population densities in 1982, but leveled off at 59,304 pl/ha in 1981. Mean yield ranged from 9.1 Mg/ha (Megagrams per hectare) at 39,536 pl/ha to 11.5 Mg/ha at 69,188 pl/ha in 1982. Mean Y peaked at an average of 7.3 Mg/ha and was lowest at 39,536 pl/ha with a value of 6.3 Mg/ha in 1981. The analyses of the data on grain yield adjusted to remove the effects of barrenness (AY) were similar to those on Y. There was, apparently, a greater tendency for plants to be barren at higher densities, although the densities were not high enough for barrenness to become a substantial factor to Y. The population density means over all hybrids for per plant grain yield (PY) and per plant grain yield adjusted to remove the effects

of barrenness(PAY) are presented in Table 10 along with the means of the other traits. There is a remarkable linear trend in PY, ranging from 93 g/pl at 69,188 pl/ha in 1981 to 230 g/pl at 39,536 pl/ha in 1982.

The fact that the yield curve peaked within the range of planting densities in 1981 is largely responsible for the relatively low significance of the density effect in that year. The 1981 season had the effect of reducing the optimum population density for Y relative to that of 1982. Maximum grain yield per land area apparently was never reached in 1982, due to insufficient population density. The hybrid-by-density interaction in 1981 exhibited higher statistical significance than that of 1982, suggesting that testing hybrids at high populations in 1981 caused greater expression of differences in Y potential than testing in 1982. The correlation between the PY means and a straight line was 0.99. The similarity between the pattern of mean Ys and a reverse pattern for mean DSDs is probably no accident.

The highly significant hybrid-by-year interactions for all traits in the analysis combined over years(Table 9), compared with the less consistent pattern for hybrid-by-density interactions, strongly suggests that data taken over seasons is more useful in exposing genetic variation than is data taken over population densities. The strong influence of density in exposing genetic variation observed by Buren et al.(1974) was probably

the result of evaluating hybrids at population densities sufficient to induce substantial barrenness.

Separate analyses of variance were performed within each density for all traits whose hybrid-by-density interaction had a 0.10 level of significance. These analyses were performed by year and over years. No new information is provided by separate analyses of densities. The resulting ANOVA tables, therefore, will not be discussed, but are included in the appendix for interested readers.

#### EFFECTS OF HYBRIDS AND INBRED PARENTS

A619 X A632 had the lowest DPS in 1981, being 74.2, and Pa91 X Oh7B had the highest, being 85.4 (Table 11). Va.79:419 X Va85, the earliest flowering hybrid in 1982, shed pollen at 72.7 days post planting and B73 X H96 was the latest at 81.3 days. A619 had the earliest average pollen shed date over all crosses in both 1981 and 1982, with DPSs being 76.5 and 75.3, respectively. The experiment average for DPS in 1981 was 79.9 and was 77.3 in 1982. A619 X B73 had the highest specific combining ability in both years (Table 12), indicating that the hybrid flowered considerably later than would be predicted by the average performance of its parents in hybrid combination. Va.79:419 X Va17 had the lowest SCA effect in 1981 of -1.45 and Va.79:419 X Va85 had the lowest in 1982 with a value of -1.99. These hybrids flowered much earlier than would be ex-

Table 11. Days from planting to first pollen shed (DPS), averaged over planting densities, for the 66 hybrids (12-parent diallel) and averages for the hybrids having the indicated inbred as a common parent when grown in 1981 (above diagonal) and 1982 (below diagonal).

Inbred lines	Days from planting to first pollen shed for indicated hybrid														Average
	Va.79:419	A619	A632	B73	H93	Mo17	Va17	H60	Pa91	H96	Oh7B	Va85	Average		
Va.79:419	74.2	76.3	78.6	79.9	77.9	77.9	76.5	75.7	79.0	79.1	81.8	77.2	77.8	77.8	
A619	73.1	74.0	79.7	78.3	75.2	75.6	74.7	77.3	77.3	78.2	78.8	75.3	76.5	76.5	
A632	76.1	74.6	79.8	80.8	77.8	78.3	79.1	79.6	79.6	79.4	82.0	78.4	78.7	78.7	
B73	75.7	78.5	78.2	83.3	80.8	80.6	80.4	81.9	81.9	82.7	82.9	80.3	81.0	81.0	
H93	76.8	75.8	76.9	78.4	80.7	81.8	80.2	81.4	83.2	83.2	84.0	80.0	81.2	81.2	
Mo17	75.0	73.5	76.0	77.8	76.1	81.0	78.9	80.5	81.6	81.6	81.7	78.7	79.5	79.5	
Va17	75.4	75.5	76.8	79.0	78.4	77.4	81.0	81.1	82.2	82.2	83.1	80.6	80.2	80.2	
H60	74.8	74.0	75.0	76.4	77.2	75.9	76.5	79.6	81.3	81.3	82.4	79.3	79.3	79.3	
Pa91	77.4	76.7	77.8	79.1	78.6	78.0	78.4	82.5	85.4	85.4	81.2	80.9	80.9	80.9	
H96	76.5	77.1	77.5	81.3	78.9	79.3	79.8	80.8	83.2	83.2	80.0	81.2	81.2	81.2	
Oh7B	78.5	75.5	80.1	80.8	79.2	77.7	78.8	78.4	80.7	80.3	84.4	82.7	82.7	82.7	
Va85	72.7	74.5	75.9	76.6	78.2	76.5	76.3	77.0	78.3	78.0	79.0	79.6	79.6	79.6	
Average	75.6	75.3	76.8	78.3	77.7	76.7	77.6	76.5	78.7	78.8	79.0	76.6	76.6	76.6	
									Overall means	77.3	79.9	77.3	79.9	79.9	

Table 12. Estimates of GCA effects, SCA effects, and SCA variances of days from planting to first pollen shed (DPS), averaged over planting densities, in 1981 (above diagonal) and 1982 (below diagonal) for inbreds and hybrids from a twelve-parent diallel of maize.

		SCA effects												GCA effects	SCA variances
Inbred lines	Va.79:419	A619	A632	B73	H93	Mo17	Va17	H60	Pa91	H96	Oh7B	Va85	GCA effects	SCA variances	
Va.79:419	0.29	0.02	-0.24	0.82	0.63	-1.45	-1.28	0.29	-0.01	1.06	-0.12	-2.26	0.41		
A619	-0.23	-0.84	2.31	0.70	-0.54	-0.86	-0.79	0.06	0.65	-0.45	-0.53	-3.75	0.71		
A632	1.16	0.01	-0.03	0.73	-0.36	-0.55	1.17	-0.08	-0.59	0.33	0.19	-1.32	0.15		
B73	-0.91	2.19	0.33	0.71	0.10	-0.80	-0.14	-0.25	0.09	-1.27	-0.50	1.22	0.64		
H93	0.93	0.21	-0.28	-0.45	-0.31	0.14	-0.59	-1.04	0.33	-0.48	-1.01	1.50	0.30		
Mo17	0.27	-0.92	-0.01	0.05	-0.87	1.15	0.02	-0.07	0.66	-0.85	-0.43	-0.38	0.15		
Va17	-0.39	0.03	-0.30	0.27	0.31	0.46	1.39	-0.17	0.56	-0.17	0.75	0.32	0.59		
H60	0.22	-0.21	-0.82	-1.10	0.39	0.20	-0.22	-0.71	0.51	0.05	0.37	-0.60	0.48		
Pa91	0.42	0.02	-0.46	-0.85	-0.62	-0.14	0.66	0.44	0.06	1.33	0.58	1.07	0.18		
H96	-0.65	0.32	-0.97	1.14	-0.47	1.05	0.46	-0.38	0.30	-1.26	-1.01	1.46	0.24		
Oh7B	1.18	-1.50	1.47	0.47	-0.39	-0.72	-0.71	0.17	0.03	-0.54	1.71	3.09	0.82		
Va85	-1.99	0.09	-0.12	-1.14	1.25	0.64	-0.55	1.31	0.22	-0.26	0.57	-0.35	0.56		
GCA effects	-1.83	-2.18	-0.55	1.13	0.41	-0.71	0.33	-0.92	1.53	1.69	1.85	-0.75			
SCA variances	0.53	0.41	0.16	0.67	0.05	0.00	-0.19	0.03	-0.18	0.09	0.38	0.57			

pected from the average performance of their parents. SCA variances on average were lower in 1982, suggesting that individual hybrids deviate more from parental averages in a stressful year than in a good year. SCA variance was lowest(0.15) in Mo17 in 1981, indicating that the hybrids of this inbred are on average more consistent in time of flowering than hybrids made from other inbreds. Oh7B was influenced most by SCA effects of all the inbreds in 1981, with an SCA variance of 0.82. Va17 had the lowest SCA variance in 1982(-0.19), followed closely by Pa91(-0.18). B73 had the highest SCA variance for days to pollen shed in 1982(0.67).

B73 X H96 silked closest in time with first pollen shed of all hybrids in 1981(Table 13). A619 X H60 was most out of synchrony, with an average DSD of 9.80. In 1982 there were three hybrid which silked prior to shedding pollen(A619 X A632, A632 X H93, A632 X H96), hence their negative average DSD values. H60 X Oh7B exhibited the greatest DSD of 2.73 in 1982. H96 had the least average DSD(3.07 days) in hybrid combination under the drought conditions of 1981, followed closely by B73(3.17 days), and A619 had the most delay(6.54 days). A632 exhibited the least DSD(0.36 days) in 1982 and Va85 the most(1.95 days). Mean DSD was considerably greater in 1981 than in 1982, being 4.31 and 1.15, respectively. The lowest specific combining ability effect for DSD in 1981 was that of H93 X A619 with -1.75 days(Table 14). Other low values were associated with the other stiff-stalk(Table 1) parents crossed with A619, i.e. B73 X A619 and A632 X A619. Va.79:419, Mo17, and Va85 had the lowest SCA variances

Table 13. Days of silking delay (DSD), averaged over planting densities, for the 66 hybrids (12-parent diallel) and averages for the hybrids having the indicated inbred as a common parent when grown in 1981 (above diagonal) and 1982 (below diagonal).

Days of silking delay for indicated hybrid													
Inbred lines	Va.79:419	A619	A632	B73	H93	Mo17	Va17	H60	Pa91	H96	Ch7B	Va85	Average
Va.79:419		6.05	3.18	3.90	3.43	5.18	2.93	7.25	4.27	3.88	4.05	5.73	4.53
A619	0.63		4.40	4.08	4.18	8.97	5.15	9.80	9.77	5.47	5.33	8.70	6.54
A632	0.50	-0.28		2.17	2.28	4.38	4.35	5.40	3.58	1.72	2.57	4.25	3.48
B73	0.83	1.28	0.55		2.63	3.22	2.70	4.15	3.22	1.35	3.47	3.95	3.17
H93	0.83	1.23	-0.18	0.63		4.05	3.47	5.40	3.43	2.18	3.47	4.67	3.56
Mo17	1.07	1.60	0.40	1.27	1.57		4.00	6.42	5.17	4.80	3.73	5.18	5.01
Va17	0.67	1.18	0.30	0.72	0.92	1.28		4.95	3.48	1.95	3.17	3.62	3.62
H60	1.62	1.43	0.68	1.40	1.03	1.82	1.25		5.85	3.38	5.17	6.13	5.81
Pa91	0.85	2.02	0.67	1.18	1.15	1.70	1.92	2.28		2.72	3.10	3.95	4.41
H96	0.13	0.62	-0.29	0.65	0.65	1.60	0.24	1.13	1.22		3.45	2.88	3.07
Ch7B	1.68	1.63	1.13	2.05	1.80	2.18	1.90	2.73	2.42	1.68		3.70	3.75
Va85	1.12	1.72	0.42	0.98	0.07	2.07	1.03	0.72	1.53	0.55	2.18		4.80
Average	0.90	1.19	0.36	1.05	0.88	1.50	1.04	1.46	1.54	0.74	1.95	1.13	
											Overall means	1.15	4.31



Table 14. Estimates of GCA effects, SCA effects, and SCA variances of days of silking delay (DSD), averaged over planting densities, in 1981 (above diagonal) and 1982 (below diagonal) for the inbreds and hybrids from a twelve-parent diallel of maize.

Inbred lines	SCA effects												GCA effects	SCA variances
	Va.79:419	A619	A632	B73	H93	Mo17	Va17	H60	Pa91	H96	Oh7B	Va85		
Va.79:419		-0.95	-0.46	0.60	-0.30	-0.14	-0.86	1.05	-0.40	0.69	0.12	0.64	0.24	0.28
A619	-0.29		-1.44	-1.42	-1.75	1.44	-0.84	1.39	2.90	0.07	-0.80	1.41	2.45	2.21
A632	0.49	-0.60		0.03	-0.29	0.22	1.72	0.36	0.08	-0.32	-0.21	0.32	-0.91	0.40
B73	0.06	0.19	0.38		0.40	-0.60	0.41	-0.55	0.05	-0.34	1.04	0.36	-1.26	0.30
H93	0.24	0.33	-0.17	-0.12		-0.21	0.74	0.26	-0.17	0.06	0.60	0.64	-0.82	0.32
Mo17	-0.21	0.01	-0.27	-0.17	0.31		-0.31	-0.31	-0.02	1.09	-0.72	-0.43	0.77	0.29
Va17	-0.09	0.11	0.14	-0.20	0.18	-0.14		-0.24	-0.17	-0.23	0.24	-0.46	-0.77	0.39
H60	0.39	-0.11	0.06	0.01	-0.17	-0.07	-0.13		-0.22	-1.21	-0.17	-0.36	1.65	0.36
Pa91	-0.46	0.39	-0.04	-0.29	-0.14	-0.27	0.46	0.35		-0.34	-0.70	-1.01	0.11	0.86
H96	-0.30	-0.13	-0.13	0.05	0.24	0.50	-0.35	0.08	0.08		1.13	-0.60	-1.36	0.34
Oh7B	-0.08	-0.44	-0.02	0.13	0.06	-0.24	-0.01	0.36	-0.04	0.10		-0.52	-0.62	0.31
Va85	0.26	0.54	0.16	-0.04	-0.77	0.55	0.03	-0.76	-0.03	-0.13	0.18		0.53	0.28
GCA effects	-0.27	0.05	-0.87	-0.10	-0.29	0.40	-0.12	0.35	0.43	-0.44	0.88	-0.02		
SCA variances	0.06	0.09	0.05	0.00	0.07	0.06	0.01	0.07	0.05	0.02	0.01	0.15		

of the inbreds in 1981. The general effects of these lines, therefore, are expressed with less deviation associated with specific crosses than are the effects of other lines. A619 exhibited the greatest SCA variance in 1981(2.21). Specific effects of DSD were much smaller in 1982(Table 14). H93 X Va85 and H60 X Va85 had the lowest specific effects of -0.77 and -0.76, respectively. Mo17 X Va85 had the largest SCA effect(0.55), indicating DSD of that hybrid was half a day greater than the average delay of its parents. SCA variances for individual inbreds in 1982 were very low. The highest estimate was that for Va85 with a value of 0.15. B73 and H96 with good(low) GCA effect for DSD in 1981(-1.26 and -1.36) transmitted these effects fairly consistently, as indicated by their relatively low SCA variances.

Va.79:419 X H60 had the longest average PSI in 1981(Table 15), shedding pollen for more than 12.0 days. B73 X Mo17, Mo17 X Va85, and Va17 X Va85 had the shortest PSI, each with a mean of 7.9 days. Va.79:419 had the longest PSI in hybrid combination in 1981(10.4 days), and Oh7B had the longest PSI in 1982(7.3 days). Va17 had the shortest PSI(8.7 days) in 1981, and Va85 had the shortest(6.2 days) in 1982. Va.79:419 X A619 had the longest PSI in 1982 and Mo17 X Va85 had the shortest, with averages of 7.9 and 5.5 days, respectively. Average PSI over all hybrids was 9.2 days in 1981 and 6.8 days in 1982. Va.79:419 X H60 had the highest SCA effect for PSI in 1981(1.01) and Va.79:419 X A619 the lowest(-0.77)(Table 16), contributing to the high SCA variance of A619(0.24) and

Table 15. Pollen-shed interval in days (PSI), averaged over planting densities, for the 66 hybrids (12-parent diallel) and averages for the hybrids having the indicated inbred as a common parent when grown in 1981 (above diagonal) and 1982 (below diagonal).

Inbred lines	Pollen-shed interval (days) for indicated hybrid												Average
	Va.79:419	A619	A632	B73	H93	Mo17	Va17	H60	Pa91	H96	Oh78	Va85	
Va.79:419	10.3	7.4	5.9	10.3	10.4	10.2	9.9	12.0	11.0	10.8	10.2	9.9	10.4
A619	7.9	7.9	8.9	9.0	9.7	9.1	9.8	9.7	10.9	10.0	10.2	9.0	9.7
A632	6.2	6.6	5.9	8.8	8.2	9.0	8.6	9.5	9.7	8.7	9.1	8.4	9.0
B73	6.6	6.7	5.9	6.7	8.2	7.9	8.6	9.2	9.5	8.3	8.9	8.6	8.8
H93	7.6	7.4	5.7	6.7	6.7	8.6	8.4	9.6	9.4	8.1	9.2	9.0	9.0
Mo17	6.9	6.9	6.3	5.9	6.9	8.5	8.5	9.2	9.3	9.2	8.5	7.9	8.9
Va17	6.9	6.9	5.8	6.7	6.7	6.1	8.7	8.7	8.9	8.3	8.1	7.9	8.7
H60	8.3	7.4	6.7	6.8	7.5	7.1	6.5	9.9	9.9	9.3	9.4	9.3	9.6
Pa91	7.7	7.7	6.6	6.9	7.2	6.8	7.2	7.6	9.1	9.1	9.1	8.9	9.6
H96	7.5	6.9	6.4	6.7	6.8	6.6	6.9	7.4	7.2	9.3	9.3	8.7	9.1
Oh78	7.8	7.3	6.9	7.6	7.5	7.2	6.8	7.9	8.1	7.2		8.1	9.1
Va85	7.0	6.7	5.7	5.8	5.8	5.5	5.9	6.4	6.7	6.0	6.6		8.7
Average	7.3	7.1	6.2	6.6	6.9	6.6	6.6	7.2	7.2	6.9	7.3	6.2	Overall means 6.8

Table 16. Estimates of GCA effects, SCA effects, and SCA variances of duration of pollen shed in days (PSI), averaged over planting densities, in 1981 (above diagonal) and 1982 (below diagonal) for inbreds and hybrids from a twelve-parent diallel of maize.

Inbred lines	SCA effects												GCA effects	SCA variances
	Va.79:419	A619	A632	B73	H93	Mo17	Va17	H60	Pa91	H96	Ch7B	Va85		
Va.79:419	-0.77	-0.44	0.12	0.06	0.04	-0.09	1.01	0.01	0.34	-0.22	-0.07	1.35	0.14	
A619	0.27	-0.55	-0.36	0.19	-0.24	0.66	-0.49	0.75	0.43	0.58	-0.19	0.52	0.24	
A632	-0.47	0.07	0.27	-0.46	0.46	0.22	0.11	0.26	-0.09	0.20	0.01	-0.25	0.06	
B73	-0.52	-0.11	0.05	-0.33	-0.54	0.40	-0.04	0.25	-0.37	0.22	0.37	-0.41	0.06	
H93	0.20	0.18	-0.56	0.11	0.03	0.00	0.17	0.06	-0.73	0.41	0.59	-0.28	0.09	
Mo17	-0.13	0.08	0.38	-0.30	0.31	0.23	-0.07	0.07	0.57	-0.18	-0.38	-0.39	0.06	
Va17	-0.15	0.03	-0.11	0.46	0.14	-0.18	-0.40	-0.23	-0.20	-0.40	-0.20	-0.57	0.06	
H60	0.50	-0.14	0.09	-0.18	0.14	0.10	-0.47	-0.21	-0.20	-0.13	0.24	0.44	0.11	
Pa91	-0.14	0.10	-0.01	-0.09	-0.10	-0.16	-0.09	-0.37	-0.42	-0.19	0.43	0.06	0.06	
H96	0.15	-0.28	0.17	0.14	-0.13	0.06	0.34	0.12	-0.14	0.36	0.24	-0.16	0.11	
Ch7B	-0.08	-0.44	0.12	0.49	0.07	0.11	-0.34	0.09	0.28	-0.26	-0.42	-0.11	0.08	
Va85	0.36	0.24	0.25	-0.05	-0.37	-0.28	0.07	-0.17	0.16	-0.18	-0.03	-0.56	0.06	
GCA effects	0.52	0.30	-0.67	-0.30	0.03	-0.31	-0.30	0.43	0.44	0.02	0.55	-0.73		
SCA variances	0.07	0.01	0.04	0.05	0.03	0.01	0.04	0.02	-0.01	0.00	0.04	0.02		

Va.79:419(0.14). The highest and lowest SCA estimates in 1982 were also for two Va.79:419 hybrids, the crosses with H60 and B73, with values of 0.50 and -0.52, respectively. SCA variances of inbred lines for PSI were higher in 1981 than 1982, although not dramatically so. Va.79:419 had the largest SCA variance of the inbreds in 1982 and thus was inconsistent in transmitting its long average PSI to its hybrids.

A619 X H60 averaged -0.11 days of ASE in 1981(Table 17). This negative value does not mean that pollen was unavailable, since adjacent plots could provide pollen. A632 X H96 had the longest ASE with 7.00 days. The differences among hybrids was considerably less in 1982, with Oh7B X Va85 having the shortest ASE(4.45 days), and Va.79:419 X H96 having the longest (7.40 days). A619 had the shortest average ASE of any inbred in hybrid combination in 1981, with 3.15 days and H96 had the longest, with 6.00 days. Va.79:419 surpassed all other inbreds in 1982 with 6.42 days ASE and Mo17 and Va85 had the shortest duration with 5.06 days. Season averages across all hybrids were 4.91 days for 1981 and 5.70 days for 1982. Crosses of A619 were characterized by very high SCA effects for ASE(Table 18) compared with other inbreds in 1981 and resulted in a very high SCA variance estimate for the line(2.22). The SCA variance for Va.79:419 was the lowest with a value of 0.06. B73 had a low value of 0.16. A619 X A632 had the highest SCA effect in the 1982 season and Va.79:419 X A632 had the lowest with values of 0.68 and -0.96, respectively. Mo17 X Va85, with an SCA effect of -0.82, had the longest ear

Table 17. Days of pollen shed after first silk emergence (ASE), averaged over planting densities, for the 66 hybrids (12-parent diallel) and averages for the hybrids having the indicated inbred as a common parent when grown in 1981 (above diagonal) and 1982 (below diagonal).

Days of pollen shed after first silk emergence for indicated hybrid													
Inbred lines	Va.79:419	A619	A632	B73	H93	Mo17	Va17	H60	Pa91	H96	Oh7B	Va85	Average
Va.79:419		4.27	6.70	6.38	6.92	5.03	6.97	4.77	6.75	6.87	6.18	4.20	5.91
A619	7.30		4.53	4.88	5.47	0.14	4.67	-0.11	1.15	4.53	4.87	0.29	3.15
A632	5.73	6.83		6.67	5.95	4.65	4.27	4.12	6.08	7.00	6.48	4.17	5.51
B73	5.72	5.45	5.38		5.57	4.67	5.93	5.07	6.28	6.93	5.45	4.67	5.68
H93	6.77	6.12	5.83	6.05		4.53	4.90	4.15	6.00	5.87	5.77	4.30	5.40
Mo17	5.87	5.32	5.85	4.67	5.32		4.48	2.78	4.17	4.43	4.80	2.70	3.85
Va17	6.25	5.68	5.47	5.98	5.80	4.77		3.73	5.37	6.33	4.97	4.27	5.08
H60	6.68	6.00	6.02	5.40	6.42	5.25	5.25		4.03	5.92	4.25	3.20	3.81
Pa91	6.82	5.67	5.95	5.72	6.07	5.12	5.27	5.35		6.40	6.02	4.95	5.20
H96	7.40	6.27	6.67	6.05	6.12	5.02	6.67	6.28	5.95		5.85	5.85	6.00
Oh7B	6.15	5.62	5.72	5.53	5.70	5.02	4.85	5.18	5.70	5.47		4.42	5.37
Va85	5.88	4.93	5.28	4.78	5.72	3.47	4.85	5.67	5.18	5.40	4.45		3.91
Average	6.42	5.93	5.88	5.52	5.99	5.06	5.53	5.77	5.71	6.12	5.40	5.06	
										Overall means	5.70	5.70	4.91

Table 18. Estimates of GCA effects, SCA effects, and SCA variances of days of pollen shed after first silk emergence (ASE), averaged over planting densities, in 1981 (above diagonal) and 1982 (below diagonal) for inbreds and hybrids from a twelve-parent diallel of maize.

Inbred lines	SCA effects												GCA effects	SCA variances
	Va.79:419	A619	A632	B73	H93	Mo17	Va17	H60	Pa91	H96	Oh7B	Va85		
Va.79:419		0.18	0.02	-0.48	0.36	0.18	0.76	-0.04	0.41	-0.35	-0.34	-0.72	1.11	0.06
A619	0.56		0.89	1.05	1.94	-1.68	1.50	-1.88	-2.15	0.35	1.38	-1.59	-1.93	2.22
A632	-0.96	0.68		0.24	-0.17	0.24	-1.50	-0.25	0.19	0.23	0.40	-0.31	0.66	0.23
B73	-0.58	-0.30	-0.33		-0.74	0.07	-0.02	0.51	0.20	-0.03	-0.82	0.00	0.85	0.16
H93	-0.04	-0.15	-0.39	0.22		0.24	-0.74	-0.09	0.23	-0.79	-0.19	-0.05	0.54	0.45
Mo17	0.08	0.07	0.65	-0.13	0.00		0.54	0.24	0.10	-0.52	0.54	0.05	-1.16	0.26
Va17	-0.05	-0.08	-0.25	0.66	-0.04	-0.04		-0.16	-0.05	0.03	-0.64	0.27	0.19	0.51
H60	0.11	-0.03	0.03	-0.19	0.31	0.17	-0.35		0.01	1.02	0.04	0.60	-1.21	0.41
Pa91	0.32	-0.29	0.04	0.20	0.04	0.11	-0.26	-0.44		-0.03	0.28	0.82	0.32	0.44
H96	0.45	-0.14	0.30	0.09	-0.36	-0.44	0.69	0.04	-0.22		-0.77	0.84	1.20	0.22
Oh7B	-0.01	0.00	0.14	0.36	0.01	0.35	-0.33	-0.27	0.32	-0.36		0.10	0.51	0.30
Va85	0.10	-0.31	0.09	-0.01	0.40	-0.82	0.04	0.59	0.18	-0.05	-0.21		-1.10	0.30
GCA effects	0.79	0.25	0.21	-0.19	0.32	-0.70	-0.18	0.08	0.01	0.46	-0.33	-0.71		
SCA variances	0.14	0.06	0.17	0.07	0.01	0.09	0.08	0.04	0.01	0.08	0.02	0.08		

in this experiment. SCA variances were lowest for H93 and Pa91 in 1982. H93 had good GCA for ASE in both years.

Preflowering drought stress delayed flowering 2.6 days in 1981 compared with 1982, despite the earlier planting date in 1981. SCA variances for DSD were much higher in 1981, due at least partially to the alleviation of moisture stress half way through flowering. Mid-silking rainfall caused later hybrids to have less DSD than earlier hybrids in 1981. The range of hybrid means for anthesis-to-silking interval was greater in 1981 than in 1982. It is not certain whether this greater range can be attributed to better expression of moisture stress tolerance or is largely a result of differences in maturity. The date of anthesis and anthesis-to-silking interval were strongly negatively correlated in 1981 (Table 37). The negative estimates of SCA variance for DPS in 1982 were not necessarily due to experimental error. The effect of Va17 and Pa91 might have been to reduce the expressed GCA effects of the other lines. Such a reduction would constitute a form of epistasis. The SCA variance for DSD of A619 in 1981 was high due to its strong negative specific effects with the stiff-stalk lines and its long delay in combination with other lines. The ability to produce silks under stress explains the good performance of A632 X A619 in yield tests. The widely-held belief that pollen availability is a factor in seed set, and thus yield, was not varified by this study. Some of the poorest yielders had long PSIs in 1981 (Va.79:419 X H60, Va.79:419 X A619) and some of the best yielders had



short PSIs(B73 X Mo17, Mo17 X Va85). Va.79:419, A619, and H60 had long average PSIs in hybrid combination but low GCA effects for Y(Table 34). ASE was controlled primarily by silking delay. Despite the substantial increase in total duration of pollen shed during the droughty season of 1981, the period of pollen availability was reduced compared with 1982. The actual difference in average ASE between years was small(0.8 days). Thus pollen availability did not appear to be a limiting factor to grain yield. The low SCA variance of Va.79:419 for ASE in 1981 is in marked contrast to the high SCA variance for PSI in both years. This difference suggests that Va.79:419 adjusted PSI to accommodate silking delay. Much greater SCA variances were calculated for flowering traits in 1981 than in 1982, except for ASE, suggesting the superiority of the poorer season in discriminating genetic differences. The commercial success of B73 hybrids can be attributed partly to its ability to transmit consistently its timely silking characteristics to its hybrid progeny.

Mo17 X Va85 had the longest average EL of all hybrids in 1981, with 21.2 cm(Table 19). The longest average EL in 1982 was 21.7 cm for Mo17 X Pa91, with Mo17 X Va85 a close second at 21.6 cm. Va85 averaged the longest eared hybrids in 1981(17.1 cm) and Oh7B produced the longest average ear in hybrid combination in 1982(18.4 cm). Va.79:419 had the shortest eared hybrids in both years. Yearly averages of all hybrid in the experiment were 16.3 cm in 1981 and 17.3 cm in 1982. The very low SCA effect associated with the cross A619 X Mo17(Table 20) in 1981 (-2.25) suggests that

Table 19. Ear length in centimeters (EL), averaged over planting densities, for the 66 hybrids (12-parent diallel) and averages for the hybrids having the indicated inbred as a common parent when grown in 1981 (above diagonal) and 1982 (below diagonal).

		Ear length (cm) for indicated hybrid												
Inbred lines		Va.79:419	A619	A632	B73	H93	Mo17	Va17	H60	Pa91	H96	Ch7B	Va85	Average
Va.79:419		12.8	14.7	13.5	14.7	16.3	14.0	13.4	13.3	13.8	14.0	14.1	14.0	14.0
A619		11.6	18.1	15.8	17.0	15.8	16.3	15.8	14.3	15.0	17.8	15.3	15.8	15.8
A632		14.3	16.0	16.9	16.7	19.1	15.9	16.8	16.7	16.9	17.4	17.4	17.0	17.0
B73		13.6	15.1	16.0	15.2	18.1	16.5	18.1	16.0	15.6	15.1	17.1	16.2	16.2
H93		13.7	14.3	16.0	17.0	19.9	16.7	18.3	16.2	15.1	15.3	17.1	16.6	16.6
Mo17		15.6	18.5	18.9	19.3	18.1	18.9	18.5	18.8	16.9	19.4	21.2	18.4	18.4
Va17		14.3	16.5	17.8	19.1	17.8	21.5	14.6	16.5	14.5	15.0	17.3	16.0	16.0
H60		13.0	15.7	17.9	18.4	17.7	18.9	18.3	16.9	15.7	16.4	17.2	16.5	16.5
Pa91		15.6	14.9	18.0	18.2	16.2	21.7	17.9	18.7	16.9	15.7	17.4	16.2	16.2
H96		13.9	15.9	17.1	16.7	16.7	18.7	18.0	18.0	18.0	16.4	17.5	15.8	15.8
Ch7B		14.6	17.1	17.9	13.4	18.1	20.1	18.3	19.5	19.5	18.6	16.8	16.3	16.3
Va85		14.6	15.2	17.2	17.9	16.9	21.6	20.5	18.4	18.2	17.2	20.3	17.1	17.1
Average		14.1	15.5	17.0	17.2	16.6	19.4	18.2	17.7	17.9	17.2	18.4	18.0	18.0
											Overall means	17.3	16.3	16.3

Table 20. Estimates of GCA effects, SCA effects, and SCA variances of ear length in centimeters (EL), averaged over planting densities, in 1981 (above diagonal) and 1982 (below diagonal) for inbreds and hybrids from a twelve-parent diallel of maize.

Inbred lines	SCA effects												GCA effects	SCA variances
	Va.79:419	A619	A632	B73	H93	Mo17	Va17	H60	Pa91	H96	Ch7B	Va85		
Va.79:419		-0.43	0.17	-0.13	0.64	0.18	0.49	-0.63	-0.39	0.56	0.19	-0.63	-2.52	-0.01
A619	-0.24		1.65	0.17	0.95	-2.25	0.86	-0.20	-1.37	-0.18	2.12	-1.32	-0.58	1.56
A632	0.82	0.95		0.06	-0.56	-0.25	-0.79	-0.45	-0.20	0.41	0.42	-0.47	0.70	0.23
B73	-0.17	-0.26	-0.97		-1.17	-0.36	0.73	1.77	-0.10	0.01	-1.06	0.07	-0.17	0.41
H93	0.73	-0.30	-0.28	0.50		0.99	0.43	1.54	-0.25	-0.94	-1.26	-0.35	0.25	0.69
Mo17	-0.48	0.81	-0.36	-0.22	-0.69		0.62	-0.38	0.21	-1.23	0.82	1.64	2.32	0.94
Va17	-0.43	0.10	-0.19	0.88	0.26	0.89		-1.56	0.63	-0.99	-0.91	0.50	-0.36	0.53
H60	-1.26	-0.12	0.43	0.70	0.68	-1.11	-0.41		0.50	-0.29	-0.08	-0.21	0.20	0.68
Pa91	1.17	-1.16	0.29	0.23	-1.04	1.44	-1.08	0.27		1.17	-0.52	0.32	-0.11	0.23
H96	0.21	0.68	0.25	-0.47	0.29	-0.78	-0.21	0.42	0.18		0.64	0.83	-0.54	0.42
Ch7B	-0.39	0.50	-0.34	-0.08	0.30	-0.76	-1.21	0.53	0.27	0.24		-0.37	-0.04	0.75
Va85	0.06	-0.96	-0.60	-0.13	-0.46	1.25	1.40	-0.12	-0.57	-0.81	0.94		0.86	0.82
GCA effects	-3.51	-1.91	-0.27	-0.02	-0.74	2.30	1.02	0.47	0.70	-0.11	1.25	0.83		
SCA variances	0.27	0.26	0.14	0.08	0.13	0.62	0.45	0.26	0.55	0.03	0.18	0.48		

this would be a low yielding cross, and in fact this was the case. Both A619 and Mo17 are derived from 'Lancaster Surecrop' and this cross exhibits reduced heterosis. The ability of Va.79:419 to shorten EL consistently, especially under stress, is apparent from its GCA effect of -2.52 in 1981 and -3.51 in 1982 and its very low SCA variance(-0.01) in 1981. Pa91 and Va85 combined well with Mo17 in 1982 and Mo17 had an extremely high GCA effect for EL in both seasons (2.32 and 2.30). Va85 also had considerable SCA effect for EL in combination with Mo17 in 1981(1.64).

A619 X Mo17 had the fewest KPR on the ear in 1981(21.2), paralleling the results for EL mentioned above. Va.79:419 X A619 had the fewest KPR in 1982, with an average of 28.7. Mo17 X Va85 had the most KPR in 1981, the poor season, with an average of 39.4. Mo17 X Va17 had the maximum average KPR in 1982, with a surprising 48.1 kernels. H96, not noted as a long-eared type, gave the highest average KPR in hybrid combination of all the inbreds in 1981(35.0 kernels). As expected, Mo17 was the best on average in 1982 with 43.5 kernels per row. Overall averages of KPR in 1981 and 1982 were 32.3 and 38.8, respectively. A619 X Mo17 had an extremely low SCA effect for KPR of -9.20 in 1981(Table 22). The largest SCA effect in 1981 was observed for A619 X A632, with a value of 4.85. Thus, the high SCA variance of 14.2 for A619 is expected. Following A619 X A632 is Mo17 X Va85 with an SCA effect of 4.66. The SCA variance of Mo17 is also high(11.45), indicating that its high KPR is not inherited uniformly in its hybrids. B73 had a high GCA effect of 2.08 and a low SCA variance

Table 21. Kernels per row on the ear (KPR), averaged over planting densities, for the 66 hybrids (12-parent diallel) and averages for the hybrids having the indicated inbred as a common parent when grown in 1981 (above diagonal) and 1982 (below diagonal).

Inbred lines	Kernels per row for indicated hybrid														Average
	Va.79:419	A619	A632	B73	H93	Mo17	Va17	H60	Pa91	H96	Oh7B	Va85			
Va.79:419		25.5	29.4	29.6	31.0	32.9	29.2	24.9	26.4	31.1	30.3	26.4	28.8		
A619	28.7		34.7	32.2	33.3	21.2	30.0	23.5	23.3	31.8	34.1	26.3	28.7		
A632	32.5	35.2		35.8	33.5	37.2	29.4	28.3	35.3	37.6	36.1	33.1	33.7		
B73	32.5	35.0	36.6		33.9	35.6	36.1	35.4	32.5	35.9	35.6	33.8	34.2		
H93	32.6	29.3	35.5	40.7		38.9	33.6	32.6	34.5	35.1	33.9	34.1	34.0		
Mo17	39.0	40.3	40.0	46.3	40.6		35.1	33.2	33.3	33.2	36.3	39.4	34.2		
Va17	33.0	34.6	39.2	42.5	38.9	48.1		24.4	32.4	33.1	32.0	33.0	31.7		
H60	28.6	33.3	38.8	44.0	38.3	43.0	41.1		31.0	33.1	31.2	29.7	29.8		
Pa91	34.6	31.1	39.1	44.2	37.1	44.8	37.2	41.9		36.8	29.6	31.0	31.5		
H96	34.0	37.7	39.2	40.3	38.6	43.1	43.3	41.8	43.6		39.3	38.5	35.0		
Oh7B	35.9	38.1	40.7	45.0	43.9	47.4	40.1	43.1	44.2	45.5		33.8	33.8		
Va85	34.8	30.9	36.1	33.8	34.0	46.4	40.6	38.8	36.9	37.6	42.9		32.7		
Average	33.3	34.0	37.5	40.5	37.2	43.5	39.9	39.3	39.5	40.4	42.4	38.0	38.0	Overall means	32.3

Table 22. Estimates of GCA effects, SCA effects, and SCA variances of kernels per row on the ear (KPR), averaged over planting densities, in 1981 (above diagonal) and 1982 (below diagonal) for inbreds and hybrids from a twelve-parent diallel of maize.

Inbred lines	SCA effects												GCA effects	SCA variances
	Va.79:419	A619	A632	B73	H93	Mol7	Val7	H60	Pa91	H96	Oh7B	Va85		
Va.79:419	1.09	-0.46	-0.88	0.70	2.38	1.49	-0.73	-1.08	-0.33	0.23	-2.41	-3.91	-1.13	
A619	1.24	4.85	1.77	3.10	-9.20	2.34	-1.98	-4.09	0.45	4.10	-2.42	-3.98	14.15	
A632	1.18	3.05	-0.05	-2.19	1.32	-3.67	-2.66	2.48	0.77	0.63	-1.02	1.47	2.95	
B73	-2.12	-0.42	-2.73	-2.38	-0.89	2.47	3.86	-0.98	-1.46	-0.51	-0.95	2.08	0.61	
H93	1.56	-2.52	-0.14	1.71	2.64	0.16	1.22	1.25	-2.11	-1.92	-0.47	1.85	0.94	
Mol7	1.02	1.56	-2.60	0.35	-1.65	1.43	1.68	-0.08	-4.19	0.25	4.66	2.05	11.45	
Val7	-0.90	-0.12	0.62	0.64	2.91	-4.38	1.76	-1.45	-1.22	1.08	-0.74	2.69		
H60	-4.71	-0.83	0.84	2.68	0.70	-1.56	0.53	2.44	0.65	0.02	-0.11	-2.84	2.68	
Pa91	1.11	-3.21	0.88	2.72	-0.73	0.01	-3.52	1.72	2.47	-3.42	-0.72	-0.96	2.44	
H96	-0.56	2.39	-0.02	-2.13	-0.20	-2.68	1.55	0.60	2.19	2.35	2.86	2.98	1.79	
Oh7B	-0.78	0.57	-0.70	0.30	2.83	-0.64	-3.84	-0.30	0.58	0.97	-0.50	1.65	1.07	
Va85	2.97	-1.70	-0.37	-0.99	-2.19	3.29	1.51	0.33	-1.76	-2.10	1.00	0.35	1.15	
GCA effects	-6.07	-5.27	-1.40	1.89	-1.75	5.21	1.16	0.58	0.79	1.78	3.98	-0.90		
SCA variances	3.37	2.84	1.62	2.45	1.75	3.12	3.13	2.63	3.26	1.94	1.58	2.81		

of 0.61 in 1981. Va.79:419 had an SCA variance estimate of -1.13. The poorest specific combination for KPR in 1982 was Va.79:419 X H60, with an observed SCA effect of -4.71. The best SCA effect occurred with Mo17 X Va85 at 3.29, followed by A619 X A632 with a value of 3.05. SCA variances did not vary as much in 1982. Oh7B had a high(3.98) GCA effect and a low(1.58) SCA variance, indicating that it transmitted good kernel set relatively consistently under good seasonal conditions.

B73 X Oh7B produced the greatest average KN in 1981(Table 23) with 652 kernels. A619 X Mo17, as expected, was the poorest seed setter in 1981 with an average KN of only 289. Hybrids of H60 had the lowest average KN of 424 in 1981, while those of B73 had the highest average with 574. B73 X Oh7B topped the entries in 1982 with an average KN of 791. Va.79:419 X H60 had the poorest KN in that year with 438. Hybrids of Oh7B had the highest average KN of 676 kernels. A619 was the worst with an average KN of 524. Yearly average KNs were 517 and 597 for 1981 and 1982, respectively. A619 X A632 had the the highest specific combining ability(112) for KN in 1981(Table 24), reflecting its good SCA for KPR. Mo17 X A619 had the lowest SCA effect with a value of -150. Va.79:419 again had a negative SCA variance(-321). B73 had the highest GCA effect in 1981, averaging 63 kernels above the experiment average. Its SCA variance was low with a value of 459, indicating that its hybrids are consistently high in KN. The hybrid with the highest specific combining ability for KN in 1982 was B73 X Pa91, having a value of 135. The SCA

Table 23. Ear kernel number (KN), averaged over planting densities, for the 66 hybrids (12-parent diallel) and averages for the hybrids having the indicated inbred as a common parent when grown in 1981 (above diagonal) and 1982 (below diagonal).

Inbred lines	Ear kernel number for indicated hybrid												Average
	Va.79:419	A619	A632	B73	H93	Mo17	Va17	H60	Pa91	H96	Oh7B	Va85	
Va.79:419		462	555	574	557	516	557	419	470	544	570	492	520
A619	489		612	569	532	289	509	327	408	510	587	425	475
A632	573	563		608	494	541	477	396	593	565	623	516	544
B73	557	567	584		501	533	639	511	585	578	652	566	574
H93	545	448	516	595		512	527	439	535	528	562	516	518
Mo17	598	523	580	660	498		502	419	473	472	543	565	488
Va17	627	567	692	745	609	645		358	554	562	554	525	524
H60	438	439	512	618	499	505	604		450	466	468	415	424
Pa91	638	502	646	758	567	645	624	586		586	468	490	510
H96	583	588	580	637	559	586	695	551	684		645	551	546
Oh7B	645	617	663	791	694	666	700	594	679	704		571	568
Va85	615	464	557	635	520	612	646	511	595	563	685		512
Average	573	524	588	650	550	593	650	532	629	612	676	582	
										Overall means		597	517



Table 24. Estimates of GCA effects, SCA effects, and SCA variances of ear kernel number (KN), averaged over planting densities, in 1981 (above diagonal) and 1982 (below diagonal) for inbreds and hybrids from a twelve-parent diallel of maize.

Inbred lines	SCA effects												GCA effects	SCA variances
	Va.79:419	A619	A632	B73	H93	Mo17	Va17	H60	Pa91	H96	Oh78	Va85		
Va.79:419		-13	6	-9	35	28	29	1	-42	-7	-6	-22	3	-321
A619	9		112	34	60	-150	30	-42	-56	6	60	-41	-46	4238
A632	69	-30		-1	-54	27	-78	-49	54	-13	21	-25	29	1986
B73	-54	-80	-20		-81	-15	52	32	12	-34	17	-8	63	459
H93	117	4	3	-182		26	1	22	24	-23	-12	3	2	776
Mo17	-14	5	43	-4	-85		10	36	-4	-45	3	86	-32	2699
Va17	-15	-94	7	107	2	21		-65	37	5	-26	6	8	802
H60	-77	55	-49	115	1	-102	83		42	19	-2	5	-102	457
Pa91	4	0	91	135	-41	33	-73	23		45	-97	-14	-7	1454
H96	-53	68	-44	-57	61	15	-26	79	-14		40	8	32	-73
Oh78	-36	68	-54	53	55	6	11	-84	-119	67		4	56	748
Va85	51	-4	-17	-10	64	83	-23	-43	-39	-96	34		-6	863
GCA effects	-46	-65	39	54	-37	-13	73	-62	4	24	47	-18		
SCA variances	2950	2351	1885	8679	6159	2342	2941	5250	4603	3223	3683	2322		

of -182 for B73 X H93 was the lowest. These two inbreds are both out of 'Stiff Stalk Synthetic', and would be expected to exhibit reduced heterosis. Va17 had the highest GCA effect with a value of 73 and A619 had the lowest with -65.

Va.79:419 X B73 had the highest ear KRN of any hybrid in 1981 (Table 25), with an average of 19.4. Va.79:419 X Va17 had the highest average KRN in 1982 with 19.0 rows and the second highest in 1981 with 19.1 rows. H93 X Mo17 had the lowest KRN in both years, averaging 13.2 and 12.3, respectively. Va.79:419 had the highest average KRN in hybrid combination of all the inbreds in both years, with values of 18.0 and 17.2, respectively. Mo17 had the lowest average KRN in combination in 1981 (14.2), and H60 and Mo17 had the lowest in 1982 (13.6). The seasonal average was 16.0 in 1981 and 15.4 in 1982. In the 1981 season, A619 X A632 had the highest specific combining ability (Table 26) with a value of 1.04. Pa91 X Oh7B had the lowest SCA effect (-1.30). The SCA variances in 1981 were greater than in 1982, even though the general effects were not any larger. The highest SCA effect for KRN occurred with A632 X Va17 with a value of 0.86, and the lowest (-1.25) with Pa91 X Oh7B again. Va.79:419 was a consistently good combiner for KRN, but as we saw above, it had short ears.

The relatively small difference in average EL between 1981 and 1982 (1.0 cm) is surprising considering the large difference in KPR. The seasonal difference in KPR reflects differences in Y or KN more closely than does

Table 25. Ear kernel row number (KRN), averaged over planting densities, for the 66 hybrids (12-parent diallel) and averages for the hybrids having the indicated inbred as a common parent when grown in 1981 (above diagonal) and 1982 (below diagonal).

Inbred lines	Ear kernel row number for indicated hybrid												Average		
	Va.79:419	A619	A632	B73	H93	Mo17	Va17	H60	Pa91	H96	Oh7B	Va85			
Va.79:419	18.0	18.8	19.4	17.9	15.7	19.1	16.6	17.7	17.5	18.7	18.4	18.0			
A619	17.0	17.6	17.6	16.0	13.6	16.9	13.9	17.5	16.0	17.2	16.2	16.4			
A632	17.6	16.0	16.9	14.7	14.5	16.1	14.0	16.8	15.0	17.2	15.5	16.1			
B73	17.1	16.2	16.0	14.8	14.9	17.7	14.4	18.0	16.1	18.3	16.7	16.8			
H93	16.6	15.3	14.5	14.6	13.2	15.7	13.5	15.5	15.1	16.5	15.1	15.3			
Mo17	15.3	13.0	14.5	14.3	12.3	14.3	12.6	14.2	14.3	14.9	14.3	14.2			
Va17	19.0	16.4	17.6	17.5	15.6	13.4	14.7	17.1	16.9	17.3	15.8	16.5			
H60	15.3	13.2	13.1	14.0	13.0	11.7	14.7	14.5	14.1	15.0	14.0	14.3			
Pa91	18.4	16.0	16.5	17.2	15.2	14.4	16.7	14.0	16.0	15.8	15.8	16.2			
H96	17.1	15.6	14.8	15.8	14.4	13.6	16.0	13.2	15.7	16.4	14.3	15.6			
Oh7B	17.9	16.2	16.3	17.6	15.8	14.0	17.4	13.8	15.4	16.8	16.8	16.7			
Va85	17.7	15.0	15.4	16.4	15.3	13.2	15.9	13.2	16.1	15.0	15.9	15.7			
Average	17.2	15.4	15.7	16.1	14.8	13.6	16.4	13.6	16.0	15.1	16.0	15.4	Overall means	15.4	16.0

Table 26. Estimates of GCA effects, SCA effects, and SCA variances of ear kernel row number (KRN), averaged over planting densities, in 1981 (above diagonal) and 1982 (below diagonal) for inbreds and hybrids from a twelve-parent diallel of maize.

Inbred lines	SCA effects														GCA effects	SCA variances
	Va.79:419	A619	A632	B73	H93	Mol7	Va17	H60	Pa91	H96	Ch7B	Va85	GCA effects	SCA variances		
Va.79:419		-0.65	0.46	0.30	0.52	-0.53	0.32	0.45	-0.76	-0.27	-0.31	0.48	2.22	0.21		
A619	-0.38		1.04	0.32	0.33	-0.92	-0.07	-0.71	0.75	-0.03	-0.09	0.03	0.44	0.32		
A632	-0.03	0.29		-0.09	-0.59	0.36	-0.59	-0.26	0.37	-0.65	0.25	-0.31	0.13	0.25		
B73	-0.95	0.07	-0.41		-1.28	-0.03	0.24	-0.65	0.81	-0.37	0.63	0.12	0.88	0.31		
H93	-0.02	0.57	-0.51	-0.80		-0.08	-0.06	0.13	-0.01	0.31	0.51	0.20	-0.80	0.24		
Mol7	-0.01	-0.45	0.80	0.15	-0.45		-0.36	0.42	-0.16	0.66	0.03	0.59	-1.95	0.19		
Va17	0.56	-0.12	0.86	0.35	-0.15	-1.06		-0.03	0.29	0.78	-0.09	-0.43	0.57	0.11		
H60	-0.03	-0.19	-0.49	-0.04	0.34	0.33	0.26		0.09	0.37	0.04	0.16	-1.86	0.11		
Pa91	0.47	-0.01	0.24	0.46	-0.08	0.37	-0.34	0.01		0.13	-1.30	-0.21	0.28	0.34		
H96	0.06	0.45	-0.57	0.02	0.02	0.46	-0.18	0.10	0.00		0.02	-0.96	-0.44	0.24		
Ch7B	-0.05	0.12	0.02	0.85	0.47	0.01	0.31	-0.18	-1.25	-0.29		0.31	0.83	0.22		
Va85	0.37	-0.36	-0.21	0.31	0.61	-0.15	-0.50	-0.11	0.13	-0.08	-0.03		-0.30	0.21		
GCA effects	1.92	0.00	0.25	0.70	-0.70	-2.01	1.06	-2.05	0.58	-0.31	0.60	-0.07				
SCA variances	0.10	0.04	0.18	0.21	0.14	0.19	0.21	-0.01	0.15	0.01	0.20	0.03				

the difference in EL. The similarities were closer in 1981. The consistently large negative GCA effect for EL of Va.79:419 is largely responsible for its never being released to the seed industry and is a reflection of its disproportionately high KRN. Landi et al.(1983) suggested that a balanced expression of ear traits is necessary for maximum yield. Also, the fairly large negative SCA variance estimates for KPR(-1.13) and KN (-321) of Va.79:419 in 1981 appear to reflect a tendency to truncate the GCA effect of other lines and may not be due to experimental error. Such a truncation of KPR would be another example of epistasis or non-allelic genetic interactions. The failure of random mated populations of maize to make useful increases in grain yield under selection may be partly a result of similar interactions. Applied geneticist tend to be concerned with additive genetic effects and all other effects are assumed to be caused by dominance. The results from past variance studies on maize suggest that reassortment and recombination result in a lowering of the germplasm base to some primitive yield level. The tendency for Va.79:419 to truncate kernel set was not apparent in the more optimum season of 1982. Kernel set was more consistent with GCA effects for KN in 1982 than in 1981, as reflected in the low SCA variance for KN in 1982. Greater consistency is typical under more optimum conditions. The negative effects of reduced heterosis is also less apparent in breeding nurseries during optimum seasons. The high average KPR of H96 crosses was undoubtedly due partly to its timely silking habit. B73, another timely silker, has been noted for its ability to maintain

good kernel set under stress in combination with a wide range of germplasm. H60 would never have been useful had it not been for its acceptable performance with B73. H60 had poor GCA for both KPR and KRN. The low KRN of H93 X Mo17 and its reputation for being a stable hybrid are understandable if KRN is still negatively correlated with barrenness, as it was in the open-pollinated cultivars. The high specific combining ability of A619 X A632 for both KPR and KRN is unusual and explains the exceptional performance of the hybrid. A619 X A632 also serves to demonstrate that although ear components may be negatively correlated, as KPR and KRN are, they are not necessarily mutually exclusive. The observed yearly average difference in KN of only 80 is too small to account entirely for the yearly difference in Y. The remaining differences in Y must be explained by differences in kernel size.

The results for KW are, of course, largely dependent on KRN. The widest average kernel in 1981 was 8.3 mm from ears of H93 X H60 (Table 27), a hybrid which had one of the lowest KRN's in that year. The narrowest kernels came from Va.79:419 hybrids, specifically Va.79:419 X Oh7B with a width of 5.7 mm, followed closely by B73 X Oh7B. A619 X H60 had the widest kernels (9.6 mm) in 1982 and, again, Va.79:419 X Oh7B, along with A632 X Va17, had the narrowest (6.5 mm). The average performance of H60 hybrids was higher than those of all other inbreds for KW in both years. Averages were 7.6 mm in 1981 and 8.8 in 1982. Va.79:419 and Oh7B produced the narrowest average KW in hybrid combination in 1981 and 1982, with

Table 27. Kernel width in millimeters (KW), averaged over planting densities, for the 66 hybrids (12-parent diallel) and averages for the hybrids having the indicated inbred as a common parent when grown in 1981 (above diagonal) and 1982 (below diagonal).

Inbred lines	Kernel width (mm) for indicated hybrid												Average
	Va.79:419	A619	A632	B73	H93	Mo17	Va17	H60	Pa91	H96	Ch7B	Va85	
Va.79:419		6.58	5.78	5.85	6.24	6.53	6.12	6.57	6.39	6.08	5.65	5.96	6.16
A619	7.64		6.23	6.67	7.44	6.99	6.91	8.01	6.43	7.31	6.64	6.68	6.90
A632	6.60	7.58		6.29	6.95	6.58	6.44	7.19	6.44	7.00	5.93	6.29	6.46
B73	7.32	7.97	7.11		7.44	6.92	6.37	7.99	6.49	6.93	5.74	6.49	6.65
H93	7.34	8.18	7.74	7.98		7.80	7.33	8.33	7.37	7.16	6.64	7.34	7.28
Mo17	7.73	8.48	7.59	7.99	8.91		7.06	8.02	7.21	7.00	6.37	7.23	7.06
Va17	6.53	7.56	6.49	6.81	7.64	8.26		7.38	6.74	6.44	6.14	6.44	6.67
H60	8.24	9.57	8.77	8.68	9.11	9.46	8.18		7.80	7.42	6.89	7.39	7.55
Pa91	6.89	7.81	6.88	7.18	7.90	7.98	7.00	8.61		7.19	6.18	6.84	6.83
H96	7.30	8.05	7.48	7.64	8.11	8.29	7.53	8.89	7.84		6.34	7.50	6.94
Ch7B	6.49	7.48	6.78	6.82	7.48	7.56	6.59	8.26	7.19	7.20		6.20	6.25
Va85	6.96	8.08	7.15	7.41	8.03	8.42	7.21	9.06	7.51	7.58	7.04		6.76
Average	7.18	8.04	7.29	7.54	8.04	8.24	7.26	8.80	7.53	7.81	7.17	7.68	
										Overall means			6.79

Table 28. Estimates of GCA effects, SCA effects, and SCA variances of kernel width in millimeters (KW), averaged over planting densities, in 1981 (above diagonal) and 1982 (below diagonal) for inbreds and hybrids from a twelve-parent diallel of maize.

Inbred lines	SCA effects												GCA effects	SCA variances
	Va.79:419	A619	A632	B73	H93	Mo17	Va17	H60	Pa91	H96	Oh7B	Va85		
Va.79:419	0.36	0.04	-0.09	-0.39	0.14	0.16	-0.36	0.26	-0.18	0.16	-0.10	-0.70	0.04	
A619	0.16	-0.32	-0.08	-0.01	-0.22	0.13	0.28	-0.51	0.23	0.33	-0.19	0.12	0.07	
A632	-0.06	-0.02	0.01	-0.01	-0.15	0.14	-0.07	-0.03	0.41	0.10	-0.11	-0.36	0.02	
B73	0.38	0.10	0.05	0.27	-0.02	-0.13	0.52	-0.18	0.13	-0.30	-0.12	-0.15	0.04	
H93	-0.15	-0.24	0.14	0.11	0.17	0.14	0.18	0.01	-0.33	-0.09	0.05	0.53	0.03	
Mo17	0.02	-0.18	-0.24	-0.11	0.25	0.10	0.10	0.08	-0.26	-0.12	0.18	0.30	0.01	
Va17	-0.10	0.00	-0.25	-0.20	0.08	0.47	-0.11	0.04	-0.38	0.09	-0.18	-0.13	0.01	
H60	-0.09	0.31	0.33	-0.04	-0.16	-0.03	-0.22	0.14	-0.36	-0.13	-0.20	0.83	0.06	
Pa91	-0.04	-0.05	-0.16	-0.14	0.04	-0.11	0.00	-0.09	0.19	-0.05	0.05	0.04	0.03	
H96	0.06	-0.13	0.13	0.01	-0.07	-0.11	0.22	-0.13	0.23	-0.02	0.57	0.17	0.09	
Oh7B	-0.05	0.00	0.13	-0.10	0.00	-0.14	-0.02	-0.06	0.28	-0.02	0.04	-0.60	0.01	
Va85	-0.13	0.05	-0.06	-0.07	0.00	0.17	0.04	0.19	0.04	-0.20	-0.03	-0.04	0.01	
GCA effects	-0.58	0.36	-0.47	-0.19	0.36	0.58	-0.50	1.20	-0.21	0.10	-0.60	-0.04		
SCA variances	0.01	0.01	0.02	0.01	0.01	0.03	0.03	0.02	0.01	0.01	0.00	0.00	0.00	



values of 6.2 mm and 7.2 mm, respectively. Average yearly KWs were 6.8 mm in 1981 and 7.7 mm in 1982. H96 X Va85 had the highest SCA effect for KW of 0.57 in 1981 (Table 28) and A619 X Pa91 had the lowest of -0.51. The SCA variance of H96 (0.09) was the greatest of the inbreds in that year. In the 1982 season, Mo17 X Va17 gave the highest SCA value of 0.47. The lowest value, -0.25, was for A632 X Va17. It is not surprising that Va17, along with Mo17, had the highest SCA variance (0.3) of all the inbreds. The GCA effects for KW were noticeably higher than the SCA effects in both years. The same was true for KRN. Subsequently, the SCA variances were very low.

The highest mean KD in 1981 (Table 29), 10.8 mm, was produced by B73 X Va17 and the lowest was with A619 X Mo17 and A619 X H60, each having a value of 8.2 mm. The deepest kernels of 12.9 mm in 1982 came from H93 X Va17. The shallowest kernels in the 1982 season were on Mo17 X H60, with a mean depth of 9.7 mm. The inbred line producing the highest average KD in hybrid combination was B73 in 1981 (9.9 mm) and B73, H93, and H96 in 1982 (11.8 mm each). The inbred with the lowest average KD was H60 in both years (8.8 mm and 10.9 mm). Yearly averages for all hybrids were 9.4 mm and 11.4 mm for 1981 and 1982, respectively. Mo17 crossed with the two stiff stalk inbreds, A632 and H93, had the highest SCA effect for KD under the drought stress of 1981 with values of 0.66 for each cross (Table 30). The lowest specific combining ability effect in that year was -1.17 for both H93 X Va85 and Mo17 X H96. B73 had the highest general combining

Table 29. Kernel depth in millimeters (KD), averaged over planting densities, for the 66 hybrids (12-parent diallel) and averages for hybrids having the indicated inbred as a common parent when grown in 1981 (above diagonal) and 1982 (below diagonal).

Inbred lines	Kernel depth (mm) for indicated hybrid												Average	
	Va.79:419	A619	A632	B73	H93	Mol7	Val7	H60	Pa91	H96	Oh7B	Va85		
Va.79:419		9.2	9.2	10.1	9.9	9.0	9.5	8.4	9.8	9.2	10.1	9.9	9.5	
A619	11.6		9.3	9.0	8.9	8.2	9.0	8.2	8.9	9.2	9.1	8.4	8.9	
A632	10.9	11.4		10.1	9.9	9.9	9.8	8.4	8.8	9.6	9.9	9.3	9.5	
B73	12.0	11.2	11.4		10.0	9.7	10.8	9.4	10.1	10.6	10.2	9.3	9.9	
H93	12.1	11.6	11.4	11.6		10.1	10.3	8.8	9.9	10.2	9.8	8.3	9.6	
Mol7	11.0	10.6	11.3	11.7	11.8		9.3	8.7	9.2	8.3	9.3	9.4	9.2	
Val7	11.6	11.3	11.8	12.3	12.9	11.3		9.3	8.9	10.0	9.6	9.1	9.6	
H60	11.2	10.9	10.6	11.5	10.9	9.7	11.4		8.4	9.7	9.0	8.5	8.8	
Pa91	11.4	10.8	11.3	12.6	12.5	11.4	11.6	10.9		10.3	9.6	9.9	9.4	
H96	11.8	12.3	11.3	11.7	12.3	11.5	12.0	11.4	11.7		9.5	9.8	9.7	
Oh7B	11.1	11.3	11.1	11.9	11.6	11.2	12.1	11.3	10.7	11.9		9.7	9.6	
Va85	11.1	10.7	10.5	11.5	11.7	10.7	10.9	10.3	11.2	11.5	11.9		9.2	
Average	11.4	11.2	11.2	11.8	11.8	11.1	11.7	10.9	11.4	11.8	11.4	11.1		
									Overall means				11.4	9.4

Table 30. Estimates of GCA effects, SCA effects, and SCA variances of kernel depth in millimeters (KD), averaged over planting densities, in 1981 (above diagonal) and 1982 (below diagonal) for inbreds and hybrids from a twelve-parent diallel of maize.

Inbred lines	SCA effects												GCA effects variances
	Va.79:419	A619	A632	B73	H93	Mo17	Va17	H60	Pa91	H96	Oh78	Va85	
Va.79:419	0.36	-0.38	0.02	0.14	-0.25	-0.17	-0.41	0.29	-0.59	0.36	0.62	0.07	0.06
A619	0.34	0.38	-0.35	-0.18	-0.36	-0.03	0.05	0.12	0.15	0.09	-0.23	-0.60	-0.02
A632	-0.30	0.44	0.04	0.21	0.66	0.15	-0.40	-0.72	-0.15	0.20	0.00	0.06	0.07
B73	0.14	-0.43	-0.15	-0.24	-0.06	0.61	0.05	0.06	0.30	0.02	-0.46	0.58	0.00
H93	0.25	-0.11	-0.22	-0.64	0.66	0.38	-0.16	0.21	0.25	-0.11	-1.17	0.27	0.14
Mo17	-0.13	-0.25	0.46	0.26	0.23	-0.03	0.19	0.02	-1.17	-0.10	0.42	-0.27	0.18
Va17	-0.22	-0.31	0.30	0.16	0.62	-0.09	0.34	-0.72	0.09	-0.25	-0.37	0.22	0.05
H60	0.35	0.24	-0.05	0.22	-0.45	-0.82	0.22	-0.38	0.65	0.06	0.00	-0.67	0.02
Pa91	-0.09	-0.50	0.10	0.79	0.54	0.25	-0.01	0.59	-0.11	0.64	0.01	0.12	0.12
H96	-0.01	0.72	-0.23	-0.48	0.00	0.07	0.16	-0.18	-0.41	0.29	0.29	0.29	0.21
Oh78	-0.37	0.02	-0.11	0.10	-0.36	0.04	0.27	0.35	-0.75	0.05	0.25	0.25	-0.04
Va85	0.03	-0.17	-0.24	0.03	0.14	-0.01	-0.52	-0.20	0.11	0.07	0.76	-0.20	0.02
GCA effects	0.02	-0.17	-0.26	0.39	0.47	-0.35	0.36	-0.55	0.04	0.38	0.04	-0.37	
SCA variances	0.00	0.09	0.01	0.10	0.10	0.05	0.05	0.07	0.13	0.03	0.10	0.04	

ability effect in 1981 with a value of 0.58 and an SCA variance of 0.00. B73 X Pa91 had the highest SCA effect for KD in 1982 with a value of 0.79. Mo17 X H60 was the poorest for specific combining ability with a value of -0.82. H93 produced the best GCA in 1982(0.47).

A619 X Mo17 had the lowest average KTH in 1981(Table 31), with a value of 7.0 mm and H96 X Oh7B had the highest average, with a value of 8.2 mm. The thickest kernels in 1982 were from Va17 X Va85, with 5.1 mm, and the thinnest were from Va.79:419 X Mo17, with kernels 4.0 mm thick. The magnitude and range of the means were higher in 1981 than in 1982. The inbred lines that on average produced the thickest kernels in hybrid combination were A619 in 1981 and Va85 in 1982, with values of 5.8 mm and 4.8 mm, respectively. The lines producing the thinnest average kernels were H96 in 1981 and Va.79:419, B73, and H96 each in 1982, with values of 4.6 and 4.3 mm, respectively. The average KTH in 1981 and 1982 was 5.2 mm and 4.5 mm, respectively. A619 X Mo17 had the highest SCA effect for KTH of 1.83 in 1981(Table 32) and Mo17 X H60 had the lowest with -0.56. SCA variances of inbreds were low in 1981, with the exception of A619 and Mo17, which had values of 0.42 and 0.37, respectively. The greatest SCA effect of 1982 was produced by Mo17 X Pa91 with a value of 0.32. The lowest SCA effect of -0.33 occurred for both Va.79:419 X A619 and Va.79:419 X Va85. SCA variances were all low in 1982. In general, GCA effects were much higher in 1981 than in 1982.

Table 31. Kernel thickness in millimeters (KTH), averaged over planting densities, for the 66 hybrids (12-parent (hallel) and averages for the hybrids having the indicated inbred as a common parent when grown in 1981 (above diagonal) and 1982 (below diagonal).

Inbred lines	Kernel thickness (mm) for indicated hybrid															Average
	Va.79:419	A619	A632	B73	H93	Mo17	Val7	H60	Pa91	H96	Ch7B	Va85				
Va.79:419	5.17	5.07	4.59	4.79	5.03	4.79	5.50	5.12	4.48	4.64	5.58	4.98				
A619	4.03	5.32	4.93	5.15	8.16	5.55	6.96	6.22	4.83	5.33	6.10	5.79				
A632	4.43	4.56	4.73	5.04	5.17	5.51	6.00	4.76	4.51	4.85	5.28	5.11				
B73	4.19	4.30	4.38	4.50	5.13	4.58	5.14	4.98	4.36	4.27	5.08	4.75				
H93	4.23	4.91	4.50	4.19	5.16	4.98	5.66	4.73	4.32	4.54	5.04	4.90				
Mo17	3.99	4.59	4.74	4.18	4.46	5.55	5.68	5.66	5.22	5.51	5.42	5.61				
Val7	4.37	4.78	4.54	4.52	4.48	6.32	5.12	4.42	4.82	5.32	5.18	5.70				
H60	4.57	4.76	4.62	4.18	4.62	4.39	4.47	5.51	4.75	5.31	5.91	5.70				
Pa91	4.53	4.80	4.58	4.13	4.36	4.83	4.44	4.59	5.34	5.69	5.25	4.56				
H96	4.11	4.24	4.38	4.15	4.32	4.16	4.33	4.14	4.19	4.53	4.89	5.00				
Ch7B	4.07	4.51	4.40	4.08	4.12	4.26	4.57	4.42	4.09	4.73	5.36	4.89				
Va85	4.22	4.95	4.77	4.62	4.98	4.67	5.07	4.96	4.57	4.73	4.75	5.36				
Average	4.25	4.58	4.53	4.26	4.48	4.45	4.58	4.55	4.25	4.34	4.75	5.17	Overall means 4.46 5.17			

Table 32. Estimates of GCA effects, SCA effects, and SCA variances of kernel thickness in millimeters (KTH), averaged over planting densities, in 1981 (above diagonal) and 1982 (below diagonal) for inbreds and hybrids from a twelve-parent diallel of maize.

SCA effects														
Inbred lines	Va.79:419	A619	A632	B73	H93	Mo17	Va17	H60	Pa91	H96	Oh7B	Va85	GCA effects	SCA variances
Va.79:419		-0.47	0.18	0.10	0.13	-0.40	-0.17	-0.04	0.08	0.19	-0.01	0.41	-0.22	0.01
A619	-0.33		-0.47	-0.47	-0.40	1.83	-0.31	0.52	0.28	-0.35	-0.22	0.04	0.68	0.42
A632	0.12	-0.12		0.09	0.24	-0.42	0.40	0.31	-0.43	0.08	0.06	-0.03	-0.07	0.03
B73	0.18	-0.08	0.05		0.09	-0.06	-0.14	-0.15	0.19	0.32	-0.13	0.17	-0.46	-0.01
H93	-0.02	0.29	-0.06	-0.07		-0.19	0.11	0.20	-0.22	0.11	-0.02	-0.04	-0.30	-0.02
Mo17	-0.22	0.01	0.22	-0.05	-0.01		-0.10	-0.56	-0.07	0.24	0.17	-0.44	0.48	0.37
Va17	0.01	0.05	-0.13	0.14	0.00	-0.10		0.56	-0.14	-0.09	-0.05	-0.06	0.00	0.01
H60	0.28	0.11	0.02	-0.12	0.08	-0.11	-0.18		-0.33	-0.33	-0.14	-0.05	0.58	0.07
Pa91	0.20	0.11	-0.05	-0.22	-0.22	0.32	0.15	-0.17		0.01	0.40	0.23	0.08	0.01
H96	0.11	-0.13	0.06	0.14	0.06	0.10	-0.20	0.04	-0.19		0.00	-0.18	-0.67	-0.01
Oh7B	-0.03	0.04	-0.01	-0.03	-0.23	-0.06	0.11	0.15	-0.01	-0.01		-0.07	-0.31	-0.03
Va85	-0.33	0.04	-0.09	0.05	0.18	-0.10	0.16	-0.08	0.08	0.02	0.08		0.20	-0.03
GCA effects	-0.24	0.13	0.08	-0.22	0.02	-0.02	0.13	0.06	0.10	-0.23	-0.13	0.32		
SCA variances	0.03	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.02	0.00	0.00	0.01		

A major contributing factor to the yields of Va17, B73 and H93 was their high average KD. As stated previously, KD is the only kernel dimension not directly restricted by cob morphology. The 0.00 SCA variance of KD for B73 in 1981 is consistent with the observed stability of B73 crosses under stress. The high SCA effect of KD for B73 X Pa91 in 1982 is consistent with its reputation for being a top yielding commercial hybrid under adequate moisture. The poor average performance of H60 for KD is consistent with its poor Y performance. Average KD of hybrids appears to be as good an indicator of grain yield potential as any other component. The higher average KTH and higher average GCA effects for KTH in 1981 are probably due to single-kernel gaps caused by preflowering floret abortion. The gaps explain why EL and KPR were less closely associated in 1981 than in 1982. The very high GCA effect of KTH for Va85 in 1982 (0.32) accounts for the extremely long-eared character of Mo17 X Va85, which combines the high KPR of Mo17 with the thick kernels of Va85.

B73 X Va17 produced the greatest Y (Table 33) in 1981 (8.7 Mg/ha). Of the next four highest yielders in 1981, three were crosses with H93. B73 X Pa91 topped the entries in 1982 with an average Y of 13.0 Mg/ha or 199 bu/a. The lowest yielders were A619 X Mo17 in 1981 and Va.79:419 X A619 in 1982, with average Ys of 3.6 and 7.6 Mg/ha, respectively. H93 was the highest average yielder in hybrid combination of all the inbreds in 1981, and Va17 had the highest average in 1982, with 7.53 and 11.4 Mg/ha, respectively. The average Y across all entries in 1981 was 6.7 Mg/ha or

Table 33. Grain yield in megagrams per hectare (Y), averaged over planting densities, for the 66 hybrids (12-parent diallel) and for the hybrids having the indicated inbred as a common parent when grown in 1981 (above diagonal) and 1982 (below diagonal).

Grain yield (Mg/ha) for indicated hybrid															
Inbred lines	Va.79:419	A619	A632	B73	H93	Mo17	Va17	H60	Pa91	H96	Oh78	Va85 Average			
Va.79:419		5.2	6.6	6.8	7.4	6.2	7.1	5.3	6.2	5.7	6.0	5.8	6.2		
A619	7.6		7.5	7.1	8.1	3.6	7.5	4.7	5.3	6.2	7.6	4.8	6.1		
A632	8.7	10.6		6.6	7.3	6.8	6.5	5.5	7.4	7.8	7.3	6.3	6.9		
B73	8.9	10.2	10.0		7.1	7.1	8.7	7.9	7.7	7.8	6.8	6.9	7.3		
H93	9.0	8.6	9.6	10.4		8.1	8.2	6.7	8.3	7.3	6.9	7.5	7.5		
Mo17	9.0	9.0	10.8	11.9	9.8		6.7	5.5	5.6	5.4	6.5	8.2	6.3		
Va17	9.5	10.3	11.3	12.6	11.4	12.4		5.2	7.8	6.4	6.9	6.8	7.1		
H60	8.0	9.7	10.2	12.2	9.8	9.0	11.6		6.5	6.2	4.9	5.9	5.8		
Pa91	9.9	8.7	10.9	13.0	10.5	12.2	10.9	11.1		8.0	5.4	7.2	6.9		
H96	9.4	10.6	10.3	10.5	10.5	10.8	12.3	10.9	12.4		6.8	7.8	6.8		
Oh78	8.2	10.3	10.1	11.8	10.9	10.4	11.3	10.9	10.4	11.1		6.9	6.5		
Va85	9.2	8.4	9.3	11.5	10.8	12.5	11.8	10.7	11.1	10.2	12.1		6.8		
Average	8.9	9.5	10.2	11.2	10.1	10.7	11.4	10.4	11.0	10.8	10.7	10.7	Overall means	10.5	6.7



Table 34. Estimates of GCA effects, SCA effects, and SCA variances of grain yield in megagrams per hectare (Y), averaged over planting densities, in 1981 (above diagonal) and 1982 (below diagonal) for inbreds and hybrids from a twelve-parent diallel of maize.

Inbred lines	SCA effects														SCA effects variances	
	Va.79:419	A619	A632	B73	H93	Mo17	Va17	H60	Pa91	H96	Oh78	Va85	GCA effects	SCA effects variances		
Va.79:419	-0.30	0.21	0.00	0.30	0.38	0.49	0.09	-0.12	-0.64	0.03	-0.45	-0.54	-0.16			
A619	0.00	1.25	0.30	1.05	-2.10	0.96	-0.44	-1.00	-0.07	1.66	-1.30	-0.62	1.10			
A632	0.29	1.55	-0.99	-0.51	0.36	-0.78	-0.48	0.29	0.70	0.56	-0.61	0.19	0.22			
B73	-0.63	0.08	-0.94	-1.20	0.14	0.85	1.42	0.13	0.30	-0.45	-0.49	0.68	0.29			
H93	0.72	-0.41	-0.16	-0.51	0.83	0.18	0.06	0.55	-0.50	-0.56	-0.21	0.92	0.17			
Mo17	0.04	-0.62	0.40	0.40	-0.56	0.00	0.15	-0.86	-1.12	0.41	1.82	-0.39	0.80			
Va17	-0.25	-0.08	0.14	0.29	0.26	0.60	-0.97	0.54	-0.86	-0.06	-0.34	0.43	0.18			
H60	-0.60	0.37	0.14	1.04	-0.21	-1.67	0.22	0.57	0.28	-0.70	0.03	-0.93	0.14			
Pa91	0.63	-1.22	0.17	1.14	-0.23	0.85	-1.23	0.15	0.92	-1.32	0.30	0.18	0.26			
H96	0.27	0.84	-0.25	-1.18	0.05	-0.31	0.43	0.16	0.92	0.08	0.90	0.17	0.21			
Oh78	-0.76	0.73	-0.29	0.32	0.57	-0.63	-0.44	0.32	-0.91	-0.01	0.36	-0.17	0.33			
Va85	0.27	-1.24	-1.05	-0.01	0.47	1.49	0.05	0.09	-0.26	-0.91	1.10	0.07	0.44			
GCA effects	-1.75	-1.10	-0.32	0.79	-0.38	0.28	1.05	-0.08	0.61	0.40	0.25	0.26				
SCA variances	0.05	0.53	0.29	0.37	0.00	0.55	0.05	0.26	0.53	0.22	0.23	0.53				

102 bu/a and in 1982 was 10.5 Mg/ha or 160 bu/a. The high GCA effect for Y(0.92) of H93 in 1981(Table 34) was accompanied by a low SCA variance of 0.17. B73 also had a high GCA effect(0.68), but had a higher SCA variance of 0.29. The highest SCA reported for Y in 1981 was 1.82 for Mo17 X Va85, and the lowest was -2.10 for A619 X Mo17. Va17 was the best general combiner in 1982 with a GCA for Y of 1.05, and its progeny inherited this yield potential fairly consistently with an SCA variance of 0.05. B73 was next highest, with a GCA effect of 0.79 and a moderate SCA variance of 0.37. The highest specific combining ability for Y in 1982 was for A619 X A632(1.55), and the lowest Mo17 X H60 (-1.67).

Again, as with Y per se, the best performing hybrid for AY in 1981(Table 35) was B73 X Va17 producing 8.7 Mg/ha. The worst was A619 X Mo17 with 3.9 Mg/ha. A619 X Mo17 was one of the hybrids which experienced barrenness in 1981. The highest AY in 1982 was, as for Y above, for B73 X Pa91 and the lowest was for Va.79:419 X A619. Neither exhibited barren ears. The inbred with the highest average performance in combination for AY in 1981 was H93, with a slightly higher yield than the unadjusted value of 7.54. The best performer in 1982, Va17, had only a slightly higher AY than Y per se(11.41 versus 11.44). The worst in the two years, H60 and Va.79:419, each did slightly better with barrenness removed. Seasonal means were 6.7 and 10.5 Mg/ha, respectively, and were not affected much by barrenness. The extreme points of the results for combining ability of AY(Table 36) were essentially the same as those for Y.

**Table 35. Grain yield in megagrams per hectare adjusted to remove the effects of barrenness (AY), averaged over planting densities, for the 66 hybrids (12-parent diallel) and averages for the hybrids having the indicated inbred as a common parent when grown in 1981 (above diagonal) and 1982 (below diagonal).**

Inbred lines	Adjusted grain yield (Mg/ha) for indicated hybrid													
	Va.79:419	A619	A632	B73	H93	Mo17	Va17	H60	Pa91	H96	Oh7B	Va85	Average	
Va.79:419	5.7	6.6	6.8	7.4	6.2	7.1	5.3	6.2	5.7	6.0	5.8	6.2		
A619	7.6	7.8	7.1	8.1	3.9	7.5	5.5	5.6	6.3	7.6	5.1	6.4		
A632	8.7	10.6	6.6	7.3	7.0	6.5	5.5	7.4	7.8	7.3	6.3	6.9		
B73	9.1	10.2	10.0	7.1	7.1	8.7	7.9	7.7	7.8	6.9	6.9	7.3		
H93	9.0	8.6	9.6	10.4	8.1	8.2	6.9	8.3	7.3	6.9	7.5	7.5		
Mo17	9.0	9.0	10.8	11.9	9.8	6.8	5.5	5.6	5.4	6.5	8.2	6.4		
Va17	9.5	10.3	11.3	12.6	11.8	12.4	5.2	8.0	6.4	6.9	6.8	7.1		
H60	8.0	9.7	10.2	12.2	9.8	9.0	11.6	6.5	6.2	4.9	5.9	5.9		
Pa91	9.9	8.7	11.1	13.0	10.5	12.2	10.9	11.1	8.0	5.4	7.2	6.9		
H96	9.4	10.6	10.3	10.5	10.5	10.8	12.3	10.9	12.4	6.8	7.8	6.9		
Oh7B	8.4	10.3	10.1	11.8	10.9	10.4	11.3	10.9	10.4	11.1	6.9	6.6		
Va85	9.2	8.4	9.3	11.5	10.8	12.5	11.8	10.7	11.1	10.2	12.1	6.8		
Average	8.9	9.5	10.2	11.2	10.1	10.7	11.4	10.4	11.0	10.8	10.7	10.7	6.7	
									Overall means		10.5	6.7		

Table 36. Estimates of GCA effects, SCA effects, and SCA variances of grain yield in megagrains per hectare adjusted to remove the effects of barrenness (AY), averaged over planting densities, in 1981 (above diagonal) and 1982 (below diagonal) for inbreds and hybrids from a twelve-parent diallel of maize.

Inbred lines	SCA effects											GCA effects variances	SCA	
	Va.79:419	A619	A632	B73	H93	Mo17	Va17	H60	Pa91	H96	Oh7B			Va85
Va.79:419		-0.07	0.19	0.00	0.30	0.34	0.47	0.01	-0.15	-0.64	0.03	-0.47	-0.54	-0.16
A619	-0.02		1.27	0.09	0.85	-2.01	0.74	0.04	-0.94	-0.16	1.45	-1.25	-0.42	0.88
A632	0.25	1.55		-0.98	-0.50	0.43	-0.79	-0.55	0.27	0.71	0.57	-0.61	0.17	0.25
B73	-0.41	0.07	-0.97		-1.17	0.12	0.87	1.37	0.13	0.33	-0.27	-0.48	0.65	0.27
H93	0.66	-0.43	-0.20	-0.56		0.82	0.20	0.14	0.55	-0.46	-0.54	-0.19	0.88	0.13
Mo17	0.02	-0.60	0.40	0.39	-0.58		0.09	0.07	-0.90	-1.13	0.40	1.79	-0.39	0.78
Va17	-0.31	-0.11	0.10	0.24	0.60	0.58		-1.03	0.67	-0.84	-0.04	-0.34	0.40	0.18
H60	-0.63	0.39	0.14	1.03	-0.23	-1.65	0.20		0.49	0.24	-0.75	-0.03	-0.90	0.14
Pa91	0.59	-1.23	0.34	1.12	-0.27	0.85	-1.27	0.15		0.93	-1.33	0.29	0.17	0.28
H96	0.25	0.86	-0.25	-1.19	0.02	-0.29	0.41	0.17	0.92		0.11	0.92	0.13	0.23
Oh7B	-0.64	0.73	-0.31	0.29	0.53	-0.63	-0.47	0.32	-0.93	0.00		0.37	-0.21	0.27
Va85	0.25	-1.22	-1.05	-0.02	0.45	1.50	0.03	0.10	-0.26	-0.90	1.10		0.04	0.38
GCA effects	-1.72	-1.11	-0.32	0.80	-0.35	0.26	1.07	-0.10	0.61	0.38	0.25	0.24		
SCA variances	0.00	0.54	0.30	0.35	0.03	0.55	0.09	0.26	0.54	0.22	0.22	0.52		

Va17 has not been used much in commercial hybrids despite its high grain yield potential primarily because its poor root structure causes standability(lodging) problems. It has been used more widely as a source of germplasm for breeders. Grain yield potential, as well as consistency in crosses, resulted in the superior performance of H93 in 1981. Mo17 X Va85 had very high SCA for Y in 1981 by combining the components of high KPR(Mo17) and thick kernels (Va85). The very high SCA for Y of A619 X A632 was largely responsible for its high Y in 1982 and explains why it was widely used as a commercial hybrid at one time. The importance of specific combining ability to maximize Y was apparent. The few plants that went barren in 1982 appeared to have done so randomly, without regard for yield potential of the hybrid or for the population density. Apparently, rare ontogenetic abnormalities, not related to identifiable stress factors, caused a low background level of barrenness in this maize population. Population densities in this study were not high enough to make barrenness an important factor to Y.

The means for all traits and combining ability tables of the analyses combined over years are included in the appendix and will not be discussed.

## GENETIC CORRELATIONS

Correlations of flowering and ear traits with Y in 1981 were generally high (Table 37). The exceptions included those between mean Y and KRN; SCA effects of Y, and SCA effects of DPS and PSI; GCA effects of Y, and GCA effects of EL and KW; and mean Ys and mean KWs. The SCA correlations between KPR and Y was the highest correlation (+ or -) associated with Y, having a value of 0.87. SCA effects of KN and EL with those of Y were second, having a correlation of 0.82 for both. Other very high correlations involving Y in 1981 included GCA correlations between Y and DSD, and Y and KD, having values of -0.79 and 0.80, respectively. Adjusting to remove the effects of barrenness reduced the correlations between yield and ear components. The correlations between DSD and ear traits was highest in the GCA component, with the exception of EL, which correlated across SCA effects only. The GCA effects of DSD was correlated (negatively) most highly with GCA effects of KD, KN and KPR with values of -0.94, -0.84, and -0.74, respectively. GCA effects of KTH were positively correlated with those of DSD (0.91). Correlations between all genetic components of KTH with those of ear KN and KPR were highly negative, correlations across GCA effects being -0.84 and -0.58, respectively. The GCA correlation between KTH and Y was also highly negative (-0.65). In general, correlations with KRN were not very high, with the exception of EL (GCA correlation of -0.78) and KW (GCA correlation of -0.85), which was directly dependent on KRN. GCA effects for KD were very

Table 37. Simple correlations between traits, based on trait means and their GCA and SCA effects combined over planting densities in 1981.

Trait Source	Correlations between indicated traits <sup>a</sup>											
	AY	Y	KTH	KD	KM	KRN	KN	KPR	EL	ASE	PSI	DSD
DPS	Means	0.26x	0.32x	-0.50x	0.49x	-0.01	-0.11	0.37x	0.51x	0.14	0.45x	-0.47x
	GCA	0.49x	0.55x	-0.63x	0.65x	0.00	-0.11	0.53x	0.72x	0.20	0.51x	-0.62x
	SCA	-0.25	-0.22	0.02	0.08	-0.09	-0.15	-0.23	-0.20	-0.18	0.16	-0.30x
DSD	Means	-0.62x	-0.67x	0.80x	-0.71x	0.25	-0.22	-0.73x	-0.68x	-0.07	-0.88x	0.45x
	GCA	-0.73x	-0.79x	0.91x	-0.94x	0.35x	-0.26	-0.84x	-0.74x	0.06	-0.88x	0.46x
	SCA	-0.52x	-0.56x	0.49x	-0.24	-0.28	0.02	-0.48x	-0.57x	-0.52x	-0.89x	0.39x
PSI	Means	-0.36x	-0.36x	0.12	-0.32x	-0.17	0.37x	-0.22	-0.53x	-0.52x	0.03	
	GCA	-0.59x	-0.60x	0.18	-0.35x	-0.17	0.40x	-0.35x	-0.77x	-0.70x	0.02	
	SCA	0.01	0.04	-0.09	-0.27x	-0.15	0.24	0.14	0.07	0.06	0.07	
ASE	Means	0.50x	0.56x	-0.84x	0.63x	-0.36x	0.44x	0.70x	0.48x	-0.20		
	GCA	0.51x	0.58x	-0.93x	0.87x	-0.49x	0.51x	0.76x	0.41x	-0.45x		
	SCA	0.57x	0.63x	-0.57x	0.12	0.23	0.10	0.59x	0.65x	0.60x		
EL	Means	0.36x	0.36x	0.14	-0.09	0.44x	-0.63x	0.11	0.63x			
	GCA	0.09	0.10	0.34x	-0.21	0.49x	-0.78x	-0.16	0.54x			
	SCA	0.82x	0.82x	-0.46x	0.17	0.43x	0.06	0.75x	0.85x			
KPR	Means	0.71x	0.73x	-0.66x	0.45x	0.10	-0.18	0.73x				
	GCA	0.60x	0.64x	-0.58x	0.62x	0.02	-0.29x	0.62x				
	SCA	0.86x	0.87x	-0.82x	0.16	0.38x	0.21	0.93x				
KN	Means	0.70x	0.72x	-0.82x	0.62x	-0.50x	0.56x					
	GCA	0.64x	0.66x	-0.84x	0.91x	-0.69x	0.57x					
	SCA	0.81x	0.82x	-0.78x	0.13	0.10	0.54x					
KRN	Means	0.14	0.14	-0.40x	0.34x	-0.42x	0.42x					
	GCA	0.14	0.14	-0.43x	0.46x	-0.46x	0.46x					
	SCA	0.22	0.24	-0.32x	0.00	-0.58x						
KH	Means	0.08	0.06	0.30x	-0.31x							
	GCA	-0.05	-0.07	0.42x	-0.47x							
	SCA	0.42x	0.41x	-0.19	0.11							
KD	Means	0.54x	0.56x	-0.64x								
	GCA	0.77x	0.80x	-0.92x								
	SCA	0.30x	0.28x	-0.11								
KTH	Means	-0.58x	-0.62x									
	GCA	-0.60x	-0.65x									
	SCA	-0.59x	-0.61x									
Y	Means	0.99x										
	GCA	0.99x										
	SCA	0.99x										

<sup>a</sup> Trait codes as defined in Table 2.  
 x, xx Significant at the 0.05, and 0.01 probability level, respectively.

highly correlated with those of KN(0.91). GCA effect of ASE was most highly correlated with GCA effects of KN and KD, with values of 0.76 and 0.87, respectively. The generally positive effects of late flowering on Y and its components were almost exclusively through GCA(0.55). Curiously enough, the small SCA correlations tended to be negative and EL appeared uninfluenced by maturity. GCA effects of PSI were negatively correlated with Y(-0.60) and components associated with yield in 1981. GCA of DSD was highly negatively correlated with GCA of DPS(-0.69).

The good correlations of Y with ear traits confirm the findings of Williams et al.(1965), Russell and Teich(1967), Hallauer(1971), and El-Lakany and Russell(1971). Selecting for high SCA of ear component, especially KPR, would appear to be effective for improving Y in a droughty season. The reduced correlations between Y and ear components resulting from adjusting to remove barrenness would probably have been greater had the 1981 season been more stressful. Ear number rather than ear characters would become more important to Y as stress increased. Generally, it appears that kernel abortion rate, presumably caused largely by pre-flowering moisture stress, was influenced more by SCA effects(EL, KPR, KN); and kernel size was influenced primarily by GCA effects(KD, KTH). As Goodman(1965) observed, SCA components are greater under suboptimum seasonal conditions. The correlations between mean EL and mean Y, and between mean EL and mean KN appeared to be due exclusively to SCA effects(0.82 and 0.75, respectively), suggesting that selecting long



eared inbred lines would result in little influence on yield of their hybrids. Ear length potential, resulting in yield increase, was associated with specific hybrid combinations. Apparently, reduced DSD was a good general measure of the vigor of female floret development, judging from DSD's high negative GCA correlations with important ear components. KTH and DSD were correlated presumably because an increase in DSD was associated with discrete floret abortion that reduced longitudinal compression of kernels (Robins and Domingo, 1953). The negative GCA correlation between Y and KTH in 1981 suggests that the effect of KTH on KN was not due to competition for resources. The rate of kernel abortion dispersed within the kernel row has a great effect on the percentage of rounded kernels. Spotty abortions occur before the end of the lag phase, after which rapid linear dry matter accumulation starts (Johnson and Tanner, 1972) and such abortions have been shown to be associated with preflowering wilting by Robins and Domingo (1953). The end of the lag phase marks the time of maximum tip kernel abortion (Claassen and Shaw, 1970a). The mechanism of within-the-kernel-row abortion and tip abortion were, therefore, different in certain respects. The poor correlations with KRN in 1981 were presumably due to the good growing conditions during kernel row initiation, which occurs two or three weeks prior to flowering. Since the other components were fixed later, they were essentially controlled by different environmental and genotype-by-environment effects. The positive effect of low KRN on EL, presumably was due to the partitioning of resources and to competing sink strengths (Ottaviano and

Camussi, 1981). The high correlation between KD and KN in 1981 suggests a common mechanism for kernel set and kernel size. Either photosynthetic potential was very important or resistance to stress for both characters was essentially controlled by the same hormonal system. The most likely candidate is general cytokinin levels in the ear, which would determine its sink strength. The findings of Crane(1964) on cytokinin levels during the lag phase support this contention. Photosynthate levels are not considered limiting at the latitudes of this study(Tollenaar, 1977) and presumably were not; otherwise stalk lodging would have been more of a problem. The correlations with ASE paralleled those of DSD, but were lower. ASE was largely a function of DSD, and the above correlations are presumably explained by it. It might be construed that pollen availability was the cause of the correlated response between ASE and KN, considering the -0.93 correlation between ASE and KTH; however, its correlation with KPR was a relatively low 0.41 . ASE under stress, being largely dependent on DSD, was apparently a relative measure of the vigor of the female inflorescence. The negative correlations between PSI and components positively associated with Y in 1981 are understandable if pollen production utilized considerable nitrogen, which in hybrids with smaller, less productive tassels would go into female floret development and endosperm mitosis(Sanford et al., 1965). The negative GCA correlation between DSD and DPS is disturbing, since it implies that the effects of silking delay were confounded with those of maturity. As stated previously, moisture stress was relieved half way through silking.

Grain yield was highly correlated with EL, KPR, and KN across all three genetic components in 1982 (Table 38), having correlations between GCA effects of 0.83, 0.81, and 0.71, respectively. Surprisingly, the highly negative correlation between GCA of Y and GCA of DSD observed in 1981 disappeared in 1982, and the correlation with GCA of KD was considerably reduced. The highly positive correlation of Y with ASE in 1981 shifted to -0.63 for the GCA effects in 1982. The strong negative GCA correlations of DSD with ear components observed in 1981 disappeared in 1982. GCA effects of EL and KPR were each correlated with GCA of DSD (0.47) in 1982 in sharp contrast to the -0.74 for KPR in 1981. A small but significant negative correlation existed between SCA effects for Y and SCA effects for DSD in 1982. The strong negative correlation between GCA of KTH and GCA of Y (-0.65) observed in 1981 was not apparent in 1982 (0.13). The other negative GCA correlations of KTH with ear components of yield observed in 1981 were reduced to near zero in most cases in 1982. The GCAs for KD were positively correlated with those of Y, KN, KRN and DPS with values of 0.26, 0.49, 0.47, and 0.59, respectively. The correlation between SCA effects for KD and Y (0.54) was much higher than that based on GCA effects. Kernel width was highly negatively correlated with KRN, KN, and KD, having correlation values based on GCA effects of -0.90, -0.64, and -0.42, respectively. As expected, KRN GCA effects were positively correlated with those of KN and negatively correlated with those of EL and KPR, with values of 0.40, -0.49, and -0.41, respectively. Ear length and KPR GCA effects were positively correlated with those of KN

Table 38. Simple correlations between traits, based on trait means and their GCA and SCA effects combined over planting densities in 1982.

Trait Source	Correlations between indicated traits <sup>a</sup>											
	AY	Y	KTH	KD	KW	KRN	KN	KPR	EL	ASE	PSI	DSD
DPS	Means	0.55**	0.55**	-0.23	0.39**	-0.26*	0.11	0.43**	0.54**	0.42**	-0.14	0.06
	GCA	0.72**	0.72**	-0.33**	0.59**	-0.29*	0.12	0.69**	0.66**	0.49**	-0.17	0.06
	SCA	-0.03	-0.03	0.15	-0.18	0.05	0.10	-0.15	-0.07	-0.06	0.01	0.08
DSD	Means	0.11	0.11	0.06	-0.21	0.17	-0.21	0.36**	0.38**	-0.54**	0.47**	
	GCA	0.23	0.24	0.04	-0.25*	0.20	-0.22	0.47**	0.47**	-0.50**	0.52**	
	SCA	-0.29*	-0.30*	0.12	-0.11	-0.07	-0.15	-0.21	-0.17	-0.70**	0.21	
PSI	Means	-0.34**	-0.34**	-0.30**	0.02	0.08	0.10	-0.08	-0.17	-0.32**	0.48**	
	GCA	-0.37**	-0.37**	-0.40**	0.06	0.10	0.11	-0.38**	-0.17	-0.34**	0.47**	
	SCA	-0.27*	-0.26*	0.06	-0.09	-0.11	0.03	-0.23	-0.14	0.55**		
ASE	Means	-0.43**	-0.44**	-0.34**	0.23	-0.08	0.31*	-0.24	-0.52**	-0.68**		
	GCA	-0.62**	-0.63**	-0.45**	0.32**	-0.10	0.34**	-0.29*	-0.67**	-0.84**		
	SCA	0.05	0.06	-0.06	0.03	-0.02	0.15	-0.14	0.08	0.04		
EL	Means	0.78**	0.78**	0.24	-0.11	0.17	-0.46**	0.48**	0.89**			
	GCA	0.62**	0.63**	0.29*	-0.16	0.18	-0.49**	0.45**	0.91**			
	SCA	0.70**	0.69**	0.03	0.09	0.04	-0.07	0.35**	0.76**			
KPR	Means	0.76**	0.77**	-0.23	0.05	0.11	-0.37**	0.65**				
	GCA	0.60**	0.61**	-0.14	0.05	0.11	-0.43**	0.55**				
	SCA	0.68**	0.68**	-0.61**	0.08	0.10	-0.07	0.38**				
KN	Means	0.69**	0.69**	-0.36**	0.41**	-0.62**	0.48**					
	GCA	0.71**	0.71**	-0.20	0.48**	-0.64**	0.40**					
	SCA	0.58**	0.58**	-0.12	0.48**	-0.58**	0.44**					
KRN	Means	-0.07	-0.08	-0.19	0.41**	-0.89**						
	GCA	-0.14	-0.15	-0.24	0.47**	-0.90**						
	SCA	0.28*	0.30*	0.05	0.32**	-0.71**						
KH	Means	-0.05	-0.04	0.16	-0.36**							
	GCA	-0.06	-0.04	0.21	-0.42**							
	SCA	0.01	-0.01	-0.13	-0.22							
KD	Means	0.37**	0.36**	-0.33**								
	GCA	0.28*	0.26*	-0.47**								
	SCA	0.56**	0.54**	-0.04								
KTH	Means	0.03	0.04									
	GCA	0.13	0.13									
	SCA	-0.20	-0.20									
Y	Means	1.00**										
	GCA	1.00**										
	SCA	1.00**										

<sup>a</sup> Trait codes as defined in Table 2.  
 \*\*, \* Significant at the 0.05, and 0.01 probability level, respectively.

in 1982, with values of 0.45 and 0.55, respectively. GCA effects for KN, EL, and KPR were positively correlated with those for DPS (0.69, 0.49, and 0.66), presumably with KPR having the largest effect. GCA for late flowering was highly positively correlated with Y(0.72), and KD(0.59).

The strong effect of season on the correlations of DSD with Y and its components has not been previously investigated. The shift in the correlation of ASE with Y from positive in 1981 to negative in 1982 is understandable, since PSI was negatively correlated with Y in both years, and DSD was reduced considerably in 1982. Hybrids with longer ears will in a good season like 1982 also have longer ear shoots from which it takes longer for the silks to emerge. In general, the more basal silks emerge first. The pattern in 1982 is in contrast to that of 1981, where stress-induced silking delay dominated time of silk emergence. Its inconsistent correlation pattern across years makes KTH a poor trait on which to base selection for grain yield when screening maize germplasm. Yield advantage resulting from KD was associated with specific hybrid combinations in 1982 rather than any one inbred line. This contradicts the 1981 findings that components of kernel size were correlated mostly through GCA effects. Perhaps the components least affected by environment are the ones least influenced by SCA, consistent with Rojas and Sprague's(1952) findings. Moisture was adequate just after flowering in 1981, making good endosperm development likely. This reasoning does not explain the dominance of the GCA component of DSD in 1981, however. The

observed correlation between KD and KRN probably resulted from the lateral compression of the kernels during grain fill. Perhaps the same was partially true for KN, although the correlations with KN were higher and cannot totally be explained by KRN. The negative GCA correlations between KW and other components were also due mostly to lateral compression of the kernels. The negative GCA correlations between KRN, and EL and KPR in 1982, of course, reflected competition between florets and developing kernels for resources in the plant (Ottaviano and Camussi, 1981). Although KPR and KRN are negatively correlated, high values for each are not necessarily mutually exclusive, as can be seen in Va17, Pa91, and Oh7B crosses and in the cross A619 X A632. Va17 is an exceptional case, combining a number of good components into one inbred line. These include high GCA effects for KD and stalk rind strength (Perry, 1983), good foliar leaf disease resistance, as well as the high GCA effects for KRN and KPR. The observed importance of KPR in later maturing hybrids is consistent with the observations of Pè and Camussi (1982) that ear length is more important in later varieties. It is not surprising, then, that late flowering was correlated with Y and KD in the present study.

GCA effects of DSD under the stressful 1981 season were a better predictor of GCA effects of Y in 1982 (-0.45) (Table 39) than were GCAs of DSD in 1982 (0.24) (Table 38). GCAs of DSD in 1981 were also a better predictor of 1982 GCAs for ear components of yield, notably KD (-0.72) and KN (-0.78), with the exception of KPR and EL. Correlation between a trait in one year

Table 39. Simple correlations between traits in 1981 and those in 1982, based on trait means and their GCA and SCA effects combined over planting densities.

Trait 1981		Trait - 1982 2												
Source	AY	Y	KTH	KD	KM	KRN	KN	KPR	EL	ASE	PSI	DSD	DPS	
DPS	Means	0.55**	-0.25*	0.35**	-0.19	-0.04	0.61**	0.45**	0.52**	-0.26*	0.03	0.28*	0.86**	
	GCAs	0.68**	-0.30*	0.51**	-0.16	0.02	0.51**	0.72**	0.56**	-0.26*	0.05	0.28*	0.93**	
	SCAs	0.05	-0.11	0.23*	-0.23*	-0.28*	-0.11	0.16	0.16	-0.12	-0.09	0.06	0.33**	
DSD	Means	-0.40**	-0.39**	0.36**	-0.50**	-0.31**	-0.56**	-0.32**	-0.15	-0.08	0.27*	0.34**	-0.62**	
	GCAs	-0.46**	-0.45**	0.45**	-0.72**	-0.38**	-0.35**	-0.35**	-0.15	-0.08	0.27*	0.34**	-0.73**	
	SCAs	-0.21	-0.22	0.10	0.02	0.06	0.11	-0.20	-0.20	-0.10	0.13	0.23	-0.14	
PSI	Means	-0.58**	-0.58**	-0.15	-0.12	0.00	-0.34**	-0.57**	0.64**	0.56**	0.65**	0.06	-0.37**	
	GCAs	-0.75**	-0.75**	-0.29*	-0.21	0.21*	-0.61**	-0.45**	-0.72**	0.68**	0.75**	0.06	-0.44**	
	SCAs	-0.05	-0.05	0.28*	0.09	-0.21	0.29*	0.07	-0.16	0.14	0.16	-0.03	-0.04	
ASE	Means	0.14	0.13	-0.48**	0.50**	-0.55**	0.45**	0.06	-0.17	0.39**	0.04	-0.35**	0.50**	
	GCAs	0.11	0.10	-0.66**	0.41**	-0.63**	0.57**	0.05	-0.23	0.46**	0.06	-0.35**	0.50**	
	SCAs	0.20	0.21	0.03	-0.05	0.08	-0.09	0.08	0.14	0.18	-0.06	-0.26*	0.14	
EL	Means	0.43**	0.44**	0.34**	-0.24	-0.36**	0.03	0.54**	0.71**	-0.57**	-0.46**	0.13	0.08	
	GCAs	0.48**	0.49**	0.44**	-0.39**	-0.41**	0.11	0.64**	0.81**	-0.77**	-0.55**	0.20	0.10	
	SCAs	0.31*	0.31*	0.08	0.07	0.09	-0.02	0.05	0.17	0.01	-0.11	-0.11	0.02	
KPR	Means	0.49**	-0.17	0.29*	-0.09	-0.14	0.40**	0.56**	0.46**	-0.24	-0.38**	-0.12	0.53**	
	GCAs	0.60**	-0.23	0.38**	-0.13	-0.21	0.61**	0.69**	0.57**	-0.37**	-0.49**	-0.12	0.69**	
	SCAs	0.30*	0.29*	0.13	0.04	0.09	0.06	0.13	0.15	0.06	-0.05	-0.11	0.10	
KN	Means	0.32**	0.31*	-0.33**	-0.49**	-0.52**	0.61**	0.19	0.03	0.01	-0.18	-0.18	0.50**	
	GCAs	0.26*	0.28*	-0.46**	-0.52**	-0.52**	0.77**	0.21	0.01	-0.01	-0.24	-0.23	0.62**	
	SCAs	0.38**	0.38**	-0.03	0.21	0.27*	0.21	0.13	0.12	0.05	0.00	-0.05	0.17	
KRN	Means	-0.19	-0.20	-0.27*	0.35**	-0.72**	0.34**	-0.42**	-0.55**	0.32**	0.21	-0.11	0.04	
	GCAs	-0.29*	-0.30*	-0.53**	0.40**	-0.73**	0.28**	-0.48**	-0.60**	0.40**	0.22	-0.16	0.02	
	SCAs	0.25*	0.25*	-0.01	0.24	-0.23	0.47**	0.36**	-0.10	-0.08	0.12	0.19	0.22	
KD	Means	0.14	0.15	0.22	-0.14	0.85**	-0.45**	0.16	0.26*	-0.10	-0.05	0.05	-0.08	
	GCAs	0.17	0.18	0.30**	-0.18	0.95**	-0.42**	0.17	0.28*	-0.10	0.00	0.09	-0.07	
	SCAs	0.05	0.04	-0.11	-0.02	0.16	-0.13	0.22	0.09	-0.10	-0.33**	-0.16	-0.09	
KTH	Means	0.31*	0.30*	-0.43**	0.60**	-0.41**	0.54**	0.33	0.03	0.11	-0.09	-0.20	0.47**	
	GCAs	0.39**	0.37**	-0.53**	0.83**	-0.66**	0.58**	0.55	0.01	0.10	-0.18	-0.27*	0.70**	
	SCAs	0.17	0.17	-0.24	0.22	0.02	0.08	0.22	0.11	0.16	0.14	-0.07	-0.12	
Y	Means	-0.21	-0.20	0.49**	-0.56**	0.47**	-0.45**	-0.11	0.12	-0.25*	0.02	0.27**	-0.57**	
	GCAs	-0.21	-0.20	0.65**	-0.78**	0.57**	-0.58**	-0.14	0.16	-0.57**	0.05	0.27**	-0.68**	
	SCAs	-0.19	-0.18	0.08	-0.13	-0.02	0.03	0.01	0.05	-0.07	-0.02	0.07	-0.22	
AY	Means	0.41**	0.40**	-0.03	0.51**	-0.26*	0.32**	0.14	0.12	-0.05	0.32**	-0.26*	0.39**	
	GCAs	0.49**	0.48**	-0.04	0.77**	-0.39**	0.28*	0.18	0.15	-0.06	-0.45**	-0.26*	0.59**	
	SCAs	0.32**	0.32**	-0.02	0.21	-0.01	0.16	0.10	0.10	-0.03	-0.14	-0.08	0.06	
AY	Means	0.40**	0.39**	-0.01	0.51**	-0.24	0.28*	0.11	0.09	-0.03	0.31*	-0.27*	0.55**	
	GCAs	0.46**	0.45**	0.00	0.77**	-0.36**	0.28*	0.13	0.11	-0.04	-0.46**	-0.27*	0.55**	
	SCAs	0.33**	0.32**	-0.03	0.23	0.02	0.15	0.10	0.10	-0.01	-0.12	-0.09	0.05	

2 Trait codes as defined in Table 2.  
\*,\*\* Significant at the 0.05, and 0.01 probability level, respectively.

and the same trait in the other year were all positive and generally very high. The two notable exceptions were DSD and ASE, with correlations between means of 0.34 and 0.39. Another interesting feature of the correlations of the same trait between years was the low correlations between SCA effects. In general, low SCA correlations also were found across years among different traits. The two highest GCA correlations for the same trait across years were between DPS in each year (0.93) and, surprisingly, between KRN in each year (0.97). The generally high correlations between SCA effects of EL and SCA effects of other traits in 1981 were not repeated in the correlations of EL in 1981 with traits in 1982. The correlation between KPR in 1981 and grain Y in 1982 was a high 0.60. In contrast, the correlation between KPR in 1982 and Y in 1981 was a non-significant 0.18. GCA effects for KD in 1982 were very highly correlated with those of Y in 1981 (0.77). The same was not true for KD in 1981 and Y in 1982 (0.37). GCAs for KTH and KW were in general negatively correlated or uncorrelated with Y and components of yield, both within years and across years. Kernel depth is highly correlated with KN across years (0.74 and 0.65).

The observation that DSD under seasonal stress was a good predictor of Y in a better season has not been made by previous investigators. However, as previously noted, less silking delay was confounded with later flowering in the 1981 season due to the ending of moisture stress half way through the silking period. Mean DSD in 1981 was negatively correlated



with mean DPS in both years(-0.62 for both years). These correlations, although high, were sufficient to account for only part of the high correlations between mean DSD in 1981 and mean KD(-0.50), KW(0.49), and KN(-0.56) in 1982. The relatively low correlation between DSD in one year and DSD in the other suggests, as do the correlations of DSD with EL, that the causes of silking delay were largely different in the two seasons; the delay in 1981 being caused by stress and the delay in 1982 being due primarily to ear shoot length. The low SCA correlations across years suggest that SCA effects were more important than GCA effects in adaptation to specific seasons, as Rojas and Sprague(1952) observed. Selection for maturity and kernel row number should result in consistent progress for these traits, since they were highly correlated across years. These two traits are generally believed to be controlled by a few genes(Hallauer and Sears, 1973), and are usually fixed in the early generations of selfing. Presumably, the high SCA correlations relative to GCA correlations between EL in 1981 and other traits in 1981 were the result of specific physiological interactions occurring during that stressful season. The conclusion made previously that selection for ear length would probably be ineffective in producing consistent improvement in grain yield should be modified. Selection for ear length among inbred lines would be most effective if conditions were close to optimum for yield during the early flowering period. Under moisture stress where the planting density was above optimum, spotty floret abortions within the kernel rows made EL an inconsistent indicator of Y. This inconsistency

was the result of reductions in GCA correlations. Kernels per row appears to be a better criterion under drought stress than ear length to select for consistent grain yield across seasons. The observation that kernels per row in a productive season is not a consistent indicator of yield potential appears to contradict the early studies on open-pollinated maize, but is consistent with the findings of Williams et al.(1965), Dhillon and Singh(1977), and Pè and Camussi(1982). The very high correlations between KD in 1982 and Y in both years is an apparent exception to the observation that ear components measured in a poor season are a better predictor of grain yield in both the poor and productive seasons than are measurements taken in a productive season. Kernel depth potential may not be adequately expressed except under an optimum season, since kernel depth is the last component to be fixed in development. The conclusion that the ideal shape of a maize kernel is long and slender is unavoidable. In visually selecting ears in the breeding nursery, therefore, one should be looking for girthy, high kernel row numbered ears with many kernels per row growing on a plant that does not delay silking much under population or drought stress. This suggestion is based on the assumption that the ideal characters expressed in hybrids will also be apparent in their inbred parents, but the inbreds per se were not included in this study. The ideotype of maize proposed by Motto and Moll(1983) did not address ear characters. It is also apparent that selection based on silking and ear characteristics will be more effective as a supplement to yield testing per se for improving grain yield potential if hybrids

and inbreds are grown in a region where the climate is sub-optimum for maize production.

The correlations of data combined over years (Table 40) between GCA effects for Y with those for KPR and KD were 0.72 and 0.62, respectively. The low correlation between Y and KRN (-0.06) was unexpected. The correlation of -0.57 between DSD and Y is better than would be expected looking at the individual year data.

The low GCA correlation between KRN and Y in the combined analyses resulted from the confounding effects of early season rainfall on kernel row initials. Early season drought occurred in 1982, but it was the better season overall. Despite the good correlations over years, I would be reluctant to conclude that season, and thus climate, are not major factors in the overall effectiveness of phenotypic selection for ear components. In general, there was no discernible increase in correlations among SCA components when data were combined over years as might be expected from the observations of Matzinger et al. (1959) that high SCA variances are associated with stability over seasons.

The observed increased correlations of flowering and ear traits with Y under the effects of a poor season leads to the assumption that other stresses, such as planting density, should have a similar effect. Table 41 through 43 present the genetic correlations, broken down by densities,

Table 40. Simple correlations between traits, based on trait means and their GCA and SCA effects combined over years and planting densities.

Correlations between indicated traits <sup>2</sup>												
Trait Source	AY	Y	KTH	KD	KW	KRN	KN	KPR	EL	ASE	PSI	DSD
DPS	Means	0.55**	0.56**	-0.52**	0.50**	-0.14	-0.01	0.60**	0.47**	0.32**	-0.25*	-0.46**
	GCA	0.74**	0.76**	-0.61**	0.65**	-0.15	0.71**	0.77**	0.35**	0.36**	-0.26*	-0.50**
	SCA	-0.07	-0.06	-0.10	-0.14	0.01	-0.06	-0.04	-0.04	0.11	-0.20	-0.21
DSD	Means	-0.52**	-0.54**	0.72**	-0.65**	0.37**	-0.61**	-0.41**	-0.01	-0.78**	0.43**	
	GCA	-0.55**	-0.57**	0.79**	-0.81**	0.45**	-0.66**	-0.39**	0.07	-0.76**	0.43**	
	SCA	-0.47**	-0.50**	0.45**	-0.17	-0.26*	-0.41**	-0.54**	-0.47**	-0.86**	0.35**	
PSI	Means	-0.54**	-0.54**	-0.01	-0.17	-0.04	-0.26*	-0.53**	-0.59**	0.23		
	GCA	-0.69**	-0.70**	0.02	-0.20	-0.01	-0.28*	-0.32**	-0.66**	0.25*		
	SCA	-0.14	-0.13	0.02	-0.08	-0.34**	0.28*	-0.14	-0.12	0.18		
ASE	Means	0.18	0.20	-0.78**	0.58**	-0.42**	0.47**	0.08	-0.40**			
	GCA	0.60**	0.11	-0.86**	0.73**	-0.50**	0.48**	-0.02	-0.56**			
	SCA	0.42**	0.46**	-0.47**	0.13	0.09	0.45**	0.49**	0.43**			
EL	Means	0.57**	0.57**	0.21	-0.11	0.33**	0.21	0.79**				
	GCA	0.55**	0.55**	0.20	-0.16	0.35**	0.15	0.79**				
	SCA	0.75**	0.75**	-0.24	0.18	0.31*	0.65**	0.81**				
KPR	Means	0.71**	0.73**	-0.60**	0.32**	0.08	0.62**					
	GCA	0.71**	0.72**	-0.34**	0.24**	0.06	0.57**					
	SCA	0.61**	0.61**	-0.69**	0.26**	0.32**	0.10					
KN	Means	0.66**	0.68**	-0.69**	0.65**	-0.65**	0.65**					
	GCA	0.62**	0.63**	-0.70**	0.75**	-0.75**	0.75**					
	SCA	0.83**	0.84**	-0.65**	0.32**	-0.05	0.36**					
KRN	Means	0.01	0.01	-0.41**	0.43**	-0.86**	0.43**					
	GCA	-0.05	-0.06	-0.44**	0.49**	-0.88**	0.49**					
	SCA	0.32**	0.34**	-0.27*	0.20	-0.60**	0.20					
KH	Means	-0.02	-0.03	0.39**	-0.39**							
	GCA	-0.07	-0.08	0.47**	-0.48**							
	SCA	0.23	0.21	-0.19	-0.01							
KD	Means	0.56**	0.56**	-0.68**								
	GCA	0.61**	0.62**	-0.85**								
	SCA	0.48**	0.46**	-0.21								
KTH	Means	-0.35**	-0.37**									
	GCA	-0.30*	-0.32**									
	SCA	-0.49**	-0.50**									
Y	Means	1.00**										
	GCA	1.00**										
	SCA	1.00**										

<sup>2</sup> Trait codes as defined in Table 2.  
 \*\*, \*\* Significant at the 0.05, and 0.01 probability level, respectively.

between traits for which the hybrid-by-density interaction was significant at the 0.10 level. No substantial improvement in correlations between traits in response to higher planting density was observed in 1981 (Table 41), with the exception of the correlations with EL. These improved correlations occurred in the GCA component and carried over to a lesser degree to the hybrid mean correlations. The most prominent of these correlation shifts was the one between EL and KN, where the GCA values shift from -0.27 at 39,536 pl/ha to 0.47 at 69,188 pl/ha. Silking delay and ASE had a decline in the absolute values of correlations with EL as planting density increased in 1981. GCA correlation declined from 0.21 to -0.04 and from -0.61 to -0.26, respectively.

Apparently KPR in 1981 became more of an influence on EL as ear-tip kernel abortion increases in response to higher planting densities. Presumably such tip abortions reduced the overall effect of within-the-kernel-row abortions, which apparently do not influence ear length as much. Despite the general lack of correlation between EL and DSD in 1981, increasing planting density appears to have improved the association between tip kernel abortion, as measured by reduced KPR, and reduced silking delay. El-Lakany and Russell (1971) and Buren et al. (1974) observed a substantial increase in the correlation between pollen-shed-to-silking interval and grain yield with increasing plant density. Barrenness was an important factor in their experiments, however.

Table 41. Simple correlations between traits, based on trait means and their GCA and SCA effects within four population densities in 1981.

Trait	Density $\rho$	Source	Correlations between indicated traits $\rho$					
			AY	Y	KD	KN	EL	ASE
DSD	39,536	Means	-0.65**	-0.67**	-0.65**	-0.76**	-0.06	-0.84**
		GCAs	-0.77**	-0.79**	-0.88**	-0.86**	0.21	-0.82**
		SCAs	-0.58**	-0.61**	-0.40**	-0.59**	-0.55**	-0.88**
	49,420	Means	-0.56**	-0.58**	-0.62**	-0.61**	0.05	-0.85**
		GCAs	-0.68**	-0.69**	-0.89**	-0.79**	0.22	-0.84**
		SCAs	-0.43**	-0.47**	-0.24	-0.28*	-0.42**	-0.87**
	59,304	Means	-0.61**	-0.67**	-0.65**	-0.70**	-0.16	-0.88**
		GCAs	-0.78**	-0.83**	-0.89**	-0.81**	-0.05	-0.89**
		SCAs	-0.44**	-0.50**	-0.11	-0.47**	-0.45**	-0.84**
	69,188	Means	-0.47**	-0.60**	-0.67**	-0.68**	-0.12	-0.92**
		GCAs	-0.58**	-0.71**	-0.92**	-0.86**	-0.04	-0.93**
		SCAs	-0.40**	-0.52**	-0.19	-0.35**	-0.36**	-0.87**
ASE	39,536	Means	0.52**	0.54**	0.51**	0.69**	-0.21	
		GCAs	0.49**	0.51**	0.70**	0.72**	-0.61**	
		SCAs	0.64**	0.67**	0.29*	0.66**	0.61**	
	49,420	Means	0.41**	0.43**	0.54**	0.57**	-0.37**	
		GCAs	0.42**	0.43**	0.74**	0.69**	-0.64**	
		SCAs	0.44**	0.47**	0.25*	0.35**	0.42**	
	59,304	Means	0.54**	0.60**	0.58**	0.65**	-0.03	
		GCAs	0.59**	0.66**	0.86**	0.70**	-0.27*	
		SCAs	0.53**	0.59**	0.00	0.56**	0.56**	
	69,188	Means	0.38**	0.53**	0.64**	0.67**	-0.07	
		GCAs	0.42**	0.56**	0.94**	0.83**	-0.26*	
		SCAs	0.38**	0.55**	0.12	0.41**	0.40**	
EL	39,536	Means	0.37**	0.37**	0.01	0.14		
		GCAs	-0.05	-0.05	-0.15	-0.27*		
		SCAs	0.80**	0.82**	0.19	0.81**		
	49,420	Means	0.25*	0.26*	-0.15	-0.03		
		GCAs	-0.01	-0.01	-0.32**	-0.29*		
		SCAs	0.75**	0.75**	0.16	0.60**		
	59,304	Means	0.45**	0.46**	0.01	0.72**		
		GCAs	0.18	0.19	-0.14	0.64**		
		SCAs	0.84**	0.85**	0.30*	0.86**		
	69,188	Means	0.51**	0.48**	-0.05	0.61**		
		GCAs	0.28*	0.27*	-0.18	0.47**		
		SCAs	0.80**	0.75**	0.19	0.83**		
KN	39,536	Means	0.72**	0.73**	0.54**			
		GCAs	0.64**	0.66**	0.79**			
		SCAs	0.83**	0.85**	0.27*			
	49,420	Means	0.64**	0.65**	0.53**			
		GCAs	0.56**	0.56**	0.90**			
		SCAs	0.76**	0.77**	0.07			
	59,304	Means	0.79**	0.80**	0.66**			
		GCAs	0.77**	0.78**	0.91**			
		SCAs	0.84**	0.84**	0.23			
	69,188	Means	0.71**	0.73**	0.58**			
		GCAs	0.56**	0.64**	0.89**			
		SCAs	0.85**	0.83**	0.21			
KD	39,536	Means	0.51**	0.52**				
		GCAs	0.65**	0.67**				
		SCAs	0.43**	0.42**				
	49,420	Means	0.50**	0.50**				
		GCAs	0.80**	0.80**				
		SCAs	0.22	0.22				
	59,304	Means	0.62**	0.62**				
		GCAs	0.84**	0.86**				
		SCAs	0.39**	0.37**				
	69,188	Means	0.47**	0.51**				
		GCAs	0.62**	0.72**				
		SCAs	0.35**	0.29*				
Y	39,536	Means	1.00**					
		GCAs	1.00**					
		SCAs	1.00**					
	49,420	Means	1.00**					
		GCAs	1.00**					
		SCAs	1.00**					
	59,304	Means	0.99**					
		GCAs	0.99**					
		SCAs	0.99**					
	69,188	Means	0.96**					
		GCAs	0.98**					
		SCAs	0.95**					

$\rho$  Trait codes as defined in Table 2.

\*,\*\* Significant at the 0.05, and 0.01 probability level, respectively.

No general improvement in correlations resulted from increased planting density in 1982 (Table 42). The exceptions in this case are the GCA correlations associated with KD. The GCA correlations for KD with Y and KN declined from 0.56 to 0.21 and from 0.40 to 0.07, respectively. The correlations between hybrid means within planting densities for KPR and DSD were calculated from both years. No discernible trend in improvement of correlations was apparent, therefore the correlations are not reported.

The decline in GCA correlations with KD in 1982 probably reflected the critical function of KD in determining Y. Presumably yield potential was high enough that maximum kernel size became a major factor, especially at low planting densities. Also, there appeared to have been an association between high SCA correlations relative to GCA and positive response of GCA correlations to planting density. Kernel depth in 1982 and EL in 1981 involved this effect. The value of increased planting density for differentiating among genotypes on the basis of traits correlated with yield did not lie in improved correlations. This is contrary to the result of Buren et al. (1974) and Russell and Teich (1967). These investigators reported on several years of data at population levels where barrenness was a substantial factor in yield. The high correlations between grain yield and ear components reported herein suggest that studies on anthesis-to-silking interval should include more than just ear number per plant, as was the case for most previous studies.

Table 42. Simple correlations between traits, based on trait means and their GCA and SCA effects within four population densities in 1982.

Trait	Density a	Source	Correlations between indicated traits a				
			AY	Y	KTH	KM	KD
KN	39,536	Means	0.63**	0.62**	-0.23	-0.68**	0.48**
		GCAs	0.57**	0.55**	-0.17	-0.76**	0.56**
		SCAs	0.78**	0.80**	-0.41**	-0.41**	0.31*
	49,420	Means	0.71**	0.71**	-0.38**	-0.60**	0.45**
		GCAs	0.72**	0.72**	-0.32**	-0.65**	0.55**
		SCAs	0.68**	0.68**	-0.58**	-0.33**	0.25*
	59,304	Means	0.72**	0.73**	-0.45**	-0.58**	0.32**
		GCAs	0.71**	0.72**	-0.43**	-0.62**	0.37**
		SCAs	0.79**	0.79**	-0.51**	-0.41**	0.22
69,188	Means	0.70**	0.69**	-0.37**	-0.57**	0.22	
	GCAs	0.69**	0.68**	-0.40**	-0.63**	0.21	
	SCAs	0.75**	0.75**	-0.33**	-0.29*	0.26*	
KD	39,536	Means	0.45**	0.43**	-0.33**	-0.26*	
		GCAs	0.42**	0.40**	-0.43**	-0.29*	
		SCAs	0.50**	0.47**	-0.10	-0.20	
	49,420	Means	0.43**	0.43**	-0.33**	-0.40**	
		GCAs	0.33**	0.33**	-0.49**	-0.50**	
		SCAs	0.62**	0.62**	-0.07	-0.20	
	59,304	Means	0.30*	0.28*	-0.29*	-0.36**	
		GCAs	0.21	0.19	-0.48**	-0.42**	
		SCAs	0.46**	0.44**	0.04	-0.27*	
	69,188	Means	0.27*	0.25*	-0.18	-0.27*	
		GCAs	0.08	0.07	-0.28*	-0.39**	
		SCAs	0.53**	0.51**	-0.04	-0.01	
KM	39,536	Means	-0.04	-0.03	0.15		
		GCAs	-0.04	-0.01	0.19		
		SCAs	-0.07	-0.11	-0.09		
	49,420	Means	-0.07	-0.07	0.18		
		GCAs	-0.09	-0.09	0.23		
		SCAs	0.01	0.01	0.00		
	59,304	Means	-0.05	-0.05	0.18		
		GCAs	-0.04	-0.04	0.25*		
		SCAs	-0.12	-0.12	-0.05		
	69,188	Means	-0.03	-0.01	0.07		
		GCAs	-0.07	-0.05	0.16		
		SCAs	0.12	0.13	-0.29*		
KTH	39,536	Means	0.23	0.25*			
		GCAs	0.40**	0.44**			
		SCAs	-0.12	-0.14			
	49,420	Means	0.01	0.01			
		GCAs	0.11	0.11			
		SCAs	-0.23	-0.23			
	59,304	Means	-0.08	-0.09			
		GCAs	-0.01	-0.02			
		SCAs	-0.23	-0.24			
	69,188	Means	-0.04	-0.04			
		GCAs	0.04	0.04			
		SCAs	-0.19	-0.17			
Y	39,536	Means	0.99**				
		GCAs	1.00**				
		SCAs	0.98**				
	49,420	Means	1.00**				
		GCAs	1.00**				
		SCAs	1.00**				
	59,304	Means	1.00**				
		GCAs	1.00**				
		SCAs	1.00**				
	69,188	Means	0.99**				
		GCAs	1.00**				
		SCAs	0.99**				

a Trait codes as defined in Table 2.

\*,\*\* Significant at the 0.05, and 0.01 probability level, respectively.



Table 43. Simple correlations between traits, based on trait means and their GCA and SCA effects within four population densities combined over 1981 and 1982.

Trait	Density D	Source	Correlations between indicated traits <sup>a</sup>							
			AY	Y	KD	KM	KRN	KN	EL	ASE
DSD	39,536	Means	-0.44**	-0.46**	-0.56**	0.43**	-0.36**	-0.41**	0.14	-0.72**
		GCAs	-0.45**	-0.45**	-0.66**	0.53**	-0.49**	-0.65**	0.28*	-0.68**
		SCAs	-0.50**	-0.52**	-0.35**	-0.08	-0.06	-0.46**	-0.42**	-0.83**
	49,420	Means	-0.43**	-0.46**	-0.56**	0.26*	-0.21	-0.42**	0.08	-0.74**
		GCAs	-0.43**	-0.43**	-0.71**	0.37**	-0.29*	-0.46**	0.21	-0.70**
		SCAs	-0.44**	-0.46**	-0.24	-0.35**	0.17	-0.31*	-0.43**	-0.86**
	59,304	Means	-0.53**	-0.56**	-0.61**	0.36**	-0.27*	-0.62**	-0.10	-0.81**
		GCAs	-0.57**	-0.60**	-0.81**	0.47**	-0.32**	-0.68**	0.00	-0.80**
		SCAs	-0.48**	-0.52**	-0.06	-0.25*	0.02	-0.42**	-0.48**	-0.86**
	69,188	Means	-0.57**	-0.63**	-0.63**	0.31*	-0.18	-0.65**	-0.21	-0.85**
		GCAs	-0.69**	-0.72**	-0.85**	0.38**	-0.21	-0.75**	-0.17	-0.86**
		SCAs	-0.36**	-0.44**	-0.10	-0.19	0.08	-0.31*	-0.35**	-0.86**
ASE	39,536	Means	0.09	0.10	0.39**	-0.41**	0.49**	0.42**	-0.53**	
		GCAs	-0.08	-0.09	0.46**	-0.48**	0.63**	0.42**	-0.75**	
		SCAs	0.42**	0.45**	0.23	0.01	0.10	0.41**	0.41**	
	49,420	Means	0.04	0.05	0.48**	-0.36**	0.45**	0.29*	-0.51**	
		GCAs	-0.11	-0.10	0.58**	-0.45**	0.56**	0.48**	-0.62**	
		SCAs	0.35**	0.37**	0.28*	0.19	-0.05	0.36**	0.35**	
	59,304	Means	0.28*	0.32**	0.56**	-0.36**	0.42**	0.47**	-0.24	
		GCAs	0.31**	0.23	0.75**	-0.46**	0.49**	0.48**	-0.42**	
		SCAs	0.48**	0.52**	0.01	0.14	0.10	0.46**	0.49**	
	69,188	Means	0.34**	0.39**	0.65**	-0.41**	0.41**	0.58**	-0.12	
		GCAs	0.31**	0.60**	0.88**	-0.51**	0.48**	0.47**	-0.25*	
		SCAs	0.33*	0.40**	0.12	0.10	0.10	0.33**	0.31*	
EL	39,536	Means	0.48**	0.50**	-0.02	0.34**	-0.61**	0.05		
		GCAs	0.43**	0.44**	-0.06	0.35**	-0.67**	-0.09		
		SCAs	0.71**	0.72**	0.12	0.28*	0.00	0.64**		
	49,420	Means	0.56**	0.54**	-0.12	0.36**	-0.63**	0.17		
		GCAs	0.53**	0.52**	-0.23	0.37**	-0.68**	0.09		
		SCAs	0.69**	0.70**	0.25*	0.26*	-0.11	0.58**		
	59,304	Means	0.58**	0.58**	-0.11	0.32**	-0.59**	0.33**		
		GCAs	0.57**	0.57**	-0.22	0.32**	-0.66**	0.28*		
		SCAs	0.79**	0.80**	0.19	0.29*	0.02	0.70**		
	69,188	Means	0.45**	0.45**	-0.11	0.27*	-0.53**	0.37**		
		GCAs	0.43**	0.63**	-0.22	0.27*	-0.63**	0.28*		
		SCAs	0.79**	0.78**	0.19	0.27*	0.07	0.72**		
KN	39,536	Means	0.62**	0.62**	0.61**	-0.76**	0.43**			
		GCAs	0.54**	0.53**	0.73**	-0.85**	0.71**			
		SCAs	0.83**	0.85**	0.35**	-0.18	0.61**			
	49,420	Means	0.65**	0.66**	0.64**	-0.64**	0.53**			
		GCAs	0.61**	0.61**	0.76**	-0.74**	0.54**			
		SCAs	0.79**	0.80**	0.36**	-0.08	0.52**			
	59,304	Means	0.74**	0.76**	0.60**	-0.56**	0.44**			
		GCAs	0.73**	0.74**	0.72**	-0.64**	0.43**			
		SCAs	0.86**	0.85**	0.29*	-0.13	0.59**			
	69,188	Means	0.63**	0.69**	0.55**	-0.55**	0.45**			
		GCAs	0.61**	0.64**	0.68**	-0.66**	0.43**			
		SCAs	0.83**	0.82**	0.26*	-0.06	0.58**			
KRN	39,536	Means	0.05	0.04	0.27*	-0.88**				
		GCAs	0.07	0.05	0.34**	-0.90**				
		SCAs	0.35**	0.35**	0.28*	-0.71**				
	49,420	Means	0.02	0.02	0.43**	-0.87**				
		GCAs	-0.03	-0.03	0.53**	-0.89**				
		SCAs	0.28*	0.27*	0.12	-0.58**				
	59,304	Means	0.04	0.05	0.48**	-0.86**				
		GCAs	-0.04	-0.04	0.55**	-0.88**				
		SCAs	0.37**	0.37**	0.25*	-0.68**				
	69,188	Means	-0.04	-0.05	0.41**	-0.86**				
		GCAs	-0.15	-0.15	0.50**	-0.86**				
		SCAs	0.31*	0.31*	0.13	-0.66**				
KM	39,536	Means	-0.10	-0.10	-0.30**					
		GCAs	-0.17	-0.16	-0.38**					
		SCAs	0.14	0.13	-0.06					
	49,420	Means	-0.04	-0.04	-0.40**					
		GCAs	-0.10	-0.10	-0.52**					
		SCAs	0.22	0.22	0.02					
	59,304	Means	-0.04	-0.05	-0.41**					
		GCAs	-0.09	-0.11	-0.51**					
		SCAs	0.15	0.16	-0.05					
	69,188	Means	0.07	0.05	-0.32**					
		GCAs	0.03	0.02	-0.44**					
		SCAs	0.24*	0.23	0.14					
KD	39,536	Means	0.57**	0.55**						
		GCAs	0.65**	0.64**						
		SCAs	0.46**	0.43**						
	49,420	Means	0.58**	0.58**						
		GCAs	0.62**	0.62**						
		SCAs	0.51**	0.51**						
	59,304	Means	0.54**	0.53**						
		GCAs	0.59**	0.59**						
		SCAs	0.47**	0.43**						
	69,188	Means	0.49**	0.48**						
		GCAs	0.50**	0.52**						
		SCAs	0.47**	0.42**						
Y	39,536	Means	1.00**							
		GCAs	1.00**							
		SCAs	0.99**							
	49,420	Means	1.00**							
		GCAs	1.00**							
		SCAs	1.00**							
	59,304	Means	1.00**							
		GCAs	1.00**							
		SCAs	1.00**							
	69,188	Means	0.99**							
		GCAs	1.00**							
		SCAs	0.97**							

<sup>a</sup> Trait codes as defined in Table 2.  
\*,\*\* Significant at the 0.05, and 0.01 probability level, respectively.

The correlation results for traits combined over two years (Table 43) show a higher percentage of correlations exhibiting linear trend across planting rates. For example, the GCA correlations between DSD and Y improved from -0.45 to -0.72 as density increased. These improved linear trends were no doubt due both to reduced error in correlation estimates and to averaging-out of the effects of season so that density effects could be expressed. The effect of planting density in improving genetic correlations among ear and flowering traits was not substantial unless multiple-year data are used. The influence of planting density in improving correlations appeared to act through general combining ability, but not exclusively so. In contrast, the influence of adverse seasonal effects appears to increase correlations among SCA effects. The GCA correlations with DSD, an apparent exception, was influenced greatly by planting density. A possible explanation is that the physiology of seasonal resistance was the same as resistance to planting density stress. This would explain why an unfavorable season caused hybrid-by-density interaction of DSD to increase dramatically (Table 7 and Table 8).

#### HERITABILITIES AND VARIANCE COMPONENTS

The heritability estimates for both years and combined over years were very high (Table 44), consistent with the findings of Williams et al. (1965), El-Lakany and Russell (1971), and Buren et al. (1974). These high estimates were due largely to the genetic material in this study

Table 44. Estimates of combining ability variance components and upper-limit heritabilities for flowering and ear traits in 1981 and 1982, and combined over years.

Trait*	Year	Combining abilities				Heritabilities	
		GCA	(SE)	SCA	(SE)	h <sup>2</sup>	(SE)
DPS	1981	3.40	1.36	0.59	0.13	0.89	0.36
	1982	1.79	0.73	0.55	0.13	0.78	0.32
	combined	2.47	0.99	0.38	0.09	0.90	0.36
DSD	1981	1.34	0.56	0.65	0.15	0.76	0.32
	1982	0.21	0.08	0.08	0.02	0.77	0.32
	combined	0.49	0.20	0.19	0.05	0.80	0.33
PSI	1981	0.31	0.13	0.12	0.03	0.78	0.32
	1982	0.20	0.08	0.05	0.01	0.81	0.33
	combined	0.23	0.09	0.05	0.01	0.86	0.35
ASE	1981	1.05	0.44	0.56	0.13	0.75	0.31
	1982	0.19	0.08	0.11	0.03	0.69	0.29
	combined	0.41	0.17	0.17	0.04	0.79	0.33
EL	1981	1.17	0.49	0.77	0.17	0.70	0.29
	1982	2.30	0.92	0.47	0.11	0.87	0.35
	combined	1.55	0.63	0.39	0.09	0.86	0.35
KPR	1981	5.33	2.37	5.90	1.34	0.54	0.24
	1982	10.72	4.37	3.55	0.77	0.82	0.33
	combined	6.81	2.80	2.53	0.59	0.79	0.32
KRN	1981	1.35	0.54	0.26	0.06	0.90	0.36
	1982	1.33	0.53	0.17	0.04	0.91	0.36
	combined	1.33	0.53	0.16	0.04	0.93	0.37
KN	1981	0.19	0.08	0.05	0.01	0.84	0.34
	1982	0.30	0.12	0.02	0.01	0.94	0.37
	combined	0.23	0.09	0.02	0.00	0.94	0.37
KD	1981	0.12	0.05	0.15	0.04	0.49	0.22
	1982	0.10	0.05	0.12	0.03	0.52	0.23
	combined	0.11	0.05	0.08	0.02	0.63	0.27
KTH	1981	0.17	0.07	0.11	0.03	0.65	0.28
	1982	0.03	0.01	0.02	0.00	0.63	0.27
	combined	0.07	0.03	0.03	0.01	0.73	0.30
KN	1981	1834	807	1843	419	0.57	0.25
	1982	1749	881	972	939	0.70	0.35
	combined	2022	835	864	199	0.76	0.32
Y	1981	0.23	0.12	0.57	0.13	0.35	0.18
	1982	0.58	0.25	0.47	0.11	0.62	0.27
	combined	0.30	0.13	0.34	0.08	0.55	0.25
AY	1981	0.20	0.10	0.53	0.12	0.32	0.17
	1982	0.57	0.25	0.47	0.11	0.62	0.27
	combined	0.28	0.13	0.33	0.08	0.54	0.24

\* Trait codes as defined in Table 2.

being elite(selected) lines not representative of a randomly mating population of Corn Belt maize. The assumption in the model underlying the heritability estimates is that genes in the study are inherited independently. The fact that they are not, and are assumed to be, means that a large portion of variance associated with specific combinations of genes in the parents will be included in the estimates of additive variance. The numerator of the heritability estimate is twice the GCA variance component or the estimate of additive variance. In a randomly mating population at linkage equilibrium the additive variance is associated with independent gene action. The lack of independence of gene inheritance thus inflates the heritability estimates. These heritability estimates reported here(Table 44-47) are not necessarily invalid, but must be viewed as if the inbred lines in the study were discrete genetic entities and not part of a randomly mating population. We may, thus, draw inferences about genetic variation within elite material as if the inbred lines were genetically discrete. Given the current trends in maize breeding, this approach is not unrealistic. The opinion of most maize breeders that I have associated with is that recurrent selection of genetically broad based populations is ineffective in producing useful grain yield increases. Rather yield improvements tend to come out of discrete families. Studies of correlations and heritabilities may be geared to elite material, since elite lines are the desired end product. The estimates of standard error of heritability were much higher than the actual variation in heritabilities would justify. The error estimates

were based on the variance associated with the GCA component of the overall genetic variance and were not based on the experimental error. The error estimates should be considered, therefore, a maximum limit on the error level and not the actual error level(Graybill et al., 1956; Hallauer and Miranda, 1981).

The heritability of Y(Table 44) was much higher in 1982 than 1981 with values of 0.62 and 0.35, respectively. Kernel row number, KW, and DPS had two-year heritabilities of 0.93, 0.94, and 0.90, respectively. Ear length had a relatively high heritability(0.86) combined over two years. In contrast, KD had a relatively low heritability(0.63). The correlation of KD with Y was high in 1981(0.80, Table 37) and that with EL was low(0.10). The correlations in 1982(Table 38) parallel the heritabilities with values of 0.28 and 0.82, respectively. Surprisingly, the heritability for DSD was consistent over years despite the great differences in correlations associated with it from one year to the other. In general, the heritability estimates were larger in 1982 than in 1981, and those over two years were higher than those based on a single year.

The higher heritability for Y in 1982 reflects both the higher GCA variance component in 1982 and the greater experimental error in 1981. The highest heritabilities were observed in traits simply inherited. Maturity and KRN tend to be fixed early in selfing generations. The inconsistent heritability and correlation patterns across years serve to

illustrate the confounding effects of genotype-by-environment interaction that accompany any selection scheme, and indicate why conducting selection in the Corn Belt, where conditions are more optimum, may not produce the best varieties for suboptimum climates and soils. The trait wherein greatest genetic gain can be made is often not the most important to yield under a particular season. This fact is no doubt particularly applicable to this study, since the lines were selected germplasm. The increase in the heritability of DSD combined over years, despite the apparent difference in correlation patterns between the two years, is surprising. The high DSD means in 1981 combining with small underlying differences in stress induced silking delay in 1982 (the correlation between mean DSD in 1981 and 1982 being 0.34) was the probable cause of the increase. Apparently, the fewer possible factors involved in the expression of a trait, the higher the heritability. For example; KN, KD, and Y had the lowest heritabilities in 1981 with values of 0.57, and 0.49, and 0.35; respectively. The order of reduced heritability is exactly the order in which the characters are fixed in development. Kernel row number and flowering date are fixed early in development and have high heritabilities. Thus, the more independent the trait in ontogenetic terms, the higher the heritability. Low heritabilities are the result of increased numbers of dependent factors in series or in parallel. For example, yield is not only the result of a long series of development, but also a number of different components converging at once. It appears useful therefore to make selections in a breeding nursery based on traits

which are established early in plant development. The period just prior to and during flowering appears ideal because sensitivity to environment is greatest. During this period optimum brace root and ear shoot development are critical.

The GCA variance components were generally higher than the SCA components. However, the variance contributed by SCA effects in 1981 was larger than in 1982. The ratio of the GCA variance component to the SCA variance component in 1981 versus 1982 went from 2.1 to 2.6 for DSD, from 2.5 to 4.0 for PSI, from 1.5 to 4.9 for EL, from 0.9 to 3.0 for KPR, from 1.0 to 1.8 for KN, from 5.2 to 7.8 for KRN, from 3.8 to 15.0 for KW, and from 0.4 to 1.2 for Y. The exceptions were DPS and ASE which changed from 5.8 to 3.3 and 1.9 to 1.7, respectively.

The increased predominance of SCA in 1981 is consistent with the theory that SCA is largely involved in adaptation to suboptimum environments (Goodman, 1965). The ratios of variances combined over years are either on the high side, intermediate between years, or they exceed the ratios of both years. This is consistent with Rojas and Sprague (1952) who observed a substantial additive-genetic-by-environment interaction component in the SCA component of yield. The SCA component was, therefore, associated with stability of grain yield.

The estimates of combining ability variance components and heritabilities by densities in 1981 for all traits with hybrid-by-density interactions significant at the 0.10 level are presented in Table 45. Increasing planting density appears to have substantially increased the heritability of DSD from 0.64 to 0.80, KD from 0.36 to 0.56, and Y from 0.28 to 0.40. The heritabilities from 1982 (Table 46) do not show the same pattern, but rather show a reduction in the heritability of KD from 0.60 to 0.46 with increased planting rate. Improving heritabilities by increasing planting density appears effective only when accompanied by other stress, at least at the population densities of this study.

The heritability estimates by densities combined over both years (Table 47) suggest that DSD was the only trait in this study whose heritability responded consistently well to increased planting densities, with an increase from 0.77 to 0.91. This finding is consistent with the common observation that silking is the most sensitive part of maize development to environment.

Increasing planting density appeared effective in improving heritabilities of yield and ear components of yield only when planting densities are optimum or above optimum for grain yield in a season, as they were in 1981. The greater expression of genetic variation at super-optimum densities should result in greater grain yield response when selecting ear traits. The expected gain in grain yield is propor-



**Table 45. Estimates of combining ability variance components and upper-limit heritabilities for flowering and ear traits at four population densities in 1981.**

Trait*	Density (pl/ha)	Combining abilities				Heritabilities	
		GCA	(SE)	SCA	(SE)	$h^2$	(SE)
DSD	39,536	0.84	0.37	0.53	0.19	0.64	0.28
	49,420	0.93	0.41	0.71	0.19	0.65	0.28
	59,304	1.59	0.67	0.55	0.23	0.74	0.31
	69,188	2.51	1.03	0.63	0.25	0.80	0.33
ASE	39,536	0.93	0.40	0.43	0.16	0.70	0.30
	49,420	0.75	0.32	0.43	0.13	0.69	0.29
	59,304	1.26	0.53	0.63	0.20	0.71	0.30
	69,188	1.64	0.69	0.67	0.23	0.74	0.31
EL	39,536	1.12	0.50	0.94	0.30	0.59	0.26
	49,420	1.31	0.55	0.36	0.16	0.77	0.32
	59,304	1.23	0.53	0.85	0.25	0.65	0.28
	69,188	1.00	0.44	0.87	0.25	0.61	0.27
KD	39,536	0.09	0.05	0.15	0.06	0.36	0.19
	49,420	0.10	0.05	0.05	0.05	0.45	0.22
	59,304	0.18	0.08	0.12	0.05	0.59	0.26
	69,188	0.13	0.06	0.06	0.04	0.56	0.25
KN	39,536	2247	1017	1958	670	0.57	0.26
	49,420	1645	740	837	490	0.58	0.26
	59,304	2221	992	1459	604	0.59	0.27
	69,188	1457	690	1003	610	0.50	0.23
Y	39,536	0.14	0.09	0.35	0.14	0.28	0.17
	49,420	0.19	0.10	0.20	0.14	0.37	0.20
	59,304	0.37	0.20	0.74	0.25	0.37	0.20
	69,188	0.33	0.17	0.30	0.21	0.40	0.20
AY	39,536	0.13	0.08	0.32	0.14	0.27	0.17
	49,420	0.19	0.10	0.17	0.13	0.38	0.20
	59,304	0.32	0.17	0.60	0.23	0.36	0.19
	69,188	0.24	0.13	0.35	0.20	0.33	0.18

\* Trait coded as defined in Table 2.

**Table 46. Estimates of combining ability variance components and upper-limit heritabilities for ear traits at four population densities in 1982.**

Trait*	Density (pl/ha)	Combining abilities				Heritabilities	
		GCA	(SE)	SCA	(SE)	h <sup>2</sup>	(SE)
KD	39,536	0.13	0.06	0.06	0.04	0.60	0.27
	49,420	0.11	0.05	0.10	0.04	0.53	0.25
	59,304	0.12	0.06	0.07	0.04	0.57	0.26
	69,188	0.08	0.04	0.07	0.04	0.46	0.22
KN	39,536	2477	1048	1041	382	0.72	0.30
	49,420	3162	1301	474	321	0.80	0.33
	59,304	2671	1117	769	356	0.75	0.31
	69,188	2652	1098	706	292	0.78	0.32
KTH	39,536	0.03	0.01	0.01	0.00	0.74	0.31
	49,420	0.03	0.01	0.02	0.01	0.63	0.28
	59,304	0.03	0.01	0.01	0.01	0.65	0.28
	69,188	0.03	0.01	0.02	0.01	0.64	0.28
KM	39,536	0.29	0.12	0.02	0.01	0.92	0.37
	49,420	0.30	0.12	0.01	0.01	0.94	0.37
	59,304	0.30	0.12	0.03	0.01	0.91	0.36
	69,188	0.29	0.12	0.02	0.01	0.90	0.36
Y	39,536	0.33	0.15	0.34	0.10	0.56	0.26
	49,420	0.63	0.27	0.18	0.11	0.71	0.30
	59,304	0.61	0.27	0.35	0.17	0.59	0.27
	69,188	0.84	0.37	0.49	0.21	0.62	0.27
AY	39,536	0.32	0.14	0.32	0.10	0.56	0.25
	49,420	0.63	0.27	0.18	0.11	0.71	0.30
	59,304	0.62	0.28	0.37	0.17	0.60	0.27
	69,188	0.83	0.37	0.52	0.21	0.62	0.27

\* Trait coded as defined in Table 2.

Table 47. Estimates of combining ability variance components and upper-limit heritabilities for flowering and ear traits within population densities combined over two years.

Trait*	Density (pl/ha)	Combining abilities				Heritabilities	
		GCA	(SE)	SCA	(SE)	h <sup>2</sup>	(SE)
DSD	39,536	0.36	0.15	0.09	0.06	0.77	0.33
	49,420	0.39	0.17	0.16	0.07	0.75	0.32
	59,304	0.57	0.24	0.07	0.07	0.83	0.35
	69,188	0.75	0.31	-0.03	0.08	0.91	0.37
ASE	39,536	0.44	0.19	0.12	0.06	0.78	0.33
	49,420	0.33	0.14	0.13	0.06	0.74	0.32
	59,304	0.48	0.20	0.09	0.06	0.82	0.34
	69,188	0.53	0.22	0.07	0.08	0.82	0.35
EL	39,536	1.59	0.65	0.26	0.12	0.86	0.35
	49,420	1.71	0.69	0.20	0.10	0.89	0.36
	59,304	1.60	0.65	0.31	0.12	0.86	0.35
	69,188	1.31	0.54	0.36	0.13	0.82	0.34
KRN	39,536	1.49	0.59	0.17	0.05	0.92	0.37
	49,420	1.40	0.56	0.10	0.04	0.93	0.37
	59,304	1.30	0.52	0.19	0.06	0.90	0.36
	69,188	1.14	0.46	0.15	0.05	0.90	0.36
KD	39,536	0.11	0.05	0.06	0.03	0.62	0.28
	49,420	0.11	0.05	0.05	0.02	0.64	0.28
	59,304	0.14	0.06	0.07	0.03	0.68	0.29
	69,188	0.10	0.04	0.04	0.02	0.64	0.28
KN	39,536	2149	900	659	280	0.77	0.32
	49,420	2013	839	456	245	0.78	0.33
	59,304	2270	945	595	266	0.79	0.33
	69,188	1817	767	586	268	0.74	0.31
KH	39,536	0.25	0.10	0.01	0.01	0.95	0.38
	49,420	0.24	0.10	0.01	0.01	0.94	0.37
	59,304	0.22	0.09	0.02	0.01	0.93	0.37
	69,188	0.21	0.08	0.01	0.01	0.94	0.38
Y	39,536	0.16	0.07	0.13	0.06	0.54	0.26
	49,420	0.28	0.12	0.14	0.08	0.62	0.28
	59,304	0.41	0.19	0.43	0.14	0.54	0.25
	69,188	0.40	0.18	0.24	0.12	0.60	0.27
AY	39,536	0.15	0.07	0.11	0.06	0.55	0.26
	49,420	0.28	0.12	0.13	0.07	0.62	0.28
	59,304	0.38	0.18	0.38	0.13	0.55	0.25
	69,188	0.34	0.16	0.28	0.12	0.55	0.26

\* Trait codes as defined in Table 2.

tional to the product of the additive genetic correlation between grain yield and an ear trait and the square root of the heritability of the ear trait ( $r_a \times h$ ; Falconer, 1983). Screening maize germplasm for grain yield potential at super-optimum planting densities is, therefore, recommended.

## SUMMARY AND CONCLUSIONS

A diallel study of flowering and ear components of yield of Corn Belt maize was conducted at Holland, Virginia in 1981 and 1982. Sixty-six hybrids, the product of a 12-parent diallel, were planted at four population densities each year. Data were taken from five representative plants in each hybrid-density combination on a number of flowering and ear traits. These traits included days from planting to first pollen shed(DPS), anthesis-to-silking interval(DSD), pollen-shed interval(PSI), days of pollen shed after first silk emergence(ASE), ear length(EL), kernels per row on the ear(KPR), ear kernel number(KN), kernel row number(KRN), kernel width(KW), kernel depth(KD), kernel thickness(KTH), and grain yield(Y). The experiment was replicated three times. Information on the adaptability of Corn Belt maize to the soil and climatic conditions in Virginia was desired. Also desired was information on the influence of population density on expression of flowering and ear traits, their heritabilities, and their correlations with yield.

A number of hybrids, such as B73 X Va17, H93 X Pa91, and Mo17 X Va85, had Y performances substantially better than average under the drought conditions of 1981. The 1981 season, a typical droughty season in Virginia, exposed more genetic variation for Y than the 1982 season, as shown by

the broader range of hybrid means. Substantial genetic variation exists for the adaptability of Corn Belt maize to Virginia climate and soils.

Highly significant hybrid effects were found for all flowering and ear traits. Generally the hybrid effects for flowering traits were more highly significant in 1981 than 1982 and the effects for ear components were more highly significant in 1982. These facts suggest that the flowering is sensitive to moisture stress and ear components are responsive to higher yield potential.

Highly significant general(GCA) and specific combining ability(SCA) effects were found for all traits in both years, except for the SCA effects of DPS which were significant.

The effect of density was significant or highly significant for all traits in both years, except for PSI, KW, and KTH in 1982. Hybrid-by-density interactions were significant or highly significant for DSD, ASE, EL, KN, and Y in 1981, indicating that hybrids differed in their response to density for those traits under the conditions of 1981. Hybrid-by-density interactions were significant or highly significant for KN, KD, KTH, and Y in 1982.

Considering the correlations between means, GCAs, and SCAs of all traits, DSD, KPR, KN, and KD were the best traits on which to base selection for Y.

The effect of higher population density (69,000 pl/ha) on improving the correlations among traits was negligible. This absence of density effect was attributed to the population density being too low to cause substantial numbers of barren plants. Small improvements were observed in the correlations between some traits, notably correlations involving DSD, when data were combined over years.

Generally the heritabilities of all traits were high. The heritabilities were higher the earlier in plant development a trait was established. Kernel row number is the first trait to arise in ear shoot development and it had the highest heritabilities of any ear component. Combining data over years appeared to improve the heritabilities of most traits. Increasing population density consistently increased the heritability of DSD in both years. The heritabilities of other flowering traits and ear traits were improved consistently by increasing density in 1981.

The effect of season was significant or highly significant for all flowering and ear traits. Interactions between season and density effects were apparent in the hybrid-by-density interactions of DSD, ASE, and EL. In-

creased density was more effective in improving heritabilities in the sub-optimum 1981 season.

Anthesis-to-silking interval was highly negatively correlated with Y and important components of yield under the relatively droughty conditions of 1981. Hybrid-by-planting-density interaction for DSD was very high in 1981 but nonexistent in 1982. Seasonal stress induced hybrid-by-density interaction was inferred. The range of DSD means was greater in 1981 than 1982, suggesting greater discrimination among hybrids for DSD. Both the correlations of DSD with ear components and the interaction disappeared under the more favorable conditions of 1982. Also, the pattern of silking delay shifted from dependency on drought tolerance in 1981 to a slight dependency on EL in 1982. It was recommended that DSD be used as a selection criterion for grain yield improvement only under suboptimal conditions. Under more ideal conditions, selection based on DSD would be effective only if planting densities were high enough to make barrenness an important factor of yield. The heritability of DSD was high in both years despite the great differences in correlations and genotype-by-environment interactions. Silking delay in 1981 was a much better predictor of Y in 1982 than was DSD in 1982. Silking delay under environmental stress is apparently a good measure of the sink strength of the ear shoot.



Kernels per row in both seasons was found to be a good selection criterion for Y in either season. In general, means of KN reflected closely means of KPR. GCA effects for KD were very highly correlated with those of KN, suggesting a common mechanism of moisture stress tolerance for kernel set and kernel size. In general, correlation between ear components in 1981 and Y in 1982 were as high or higher than correlations between ear components in 1982 and Y in 1982. An apparent exception to this observation, kernel depth in 1982 was a better predictor of Y in 1982 than was KD in 1981. Yield potential was high but ear kernel number was lower than it might have been in 1982, due to low average KRN. This apparently created pressure to maximize kernel size and brought out more differences in kernel size potential. Kernel depth was considered the most related kernel dimension to grain yield because of its high correlations with Y and because it is the only dimension not directly restricted by cob morphology. It also represents the smallest dimension of grain fill volume; thus small changes in kernel depth produce substantial changes in volume.

Based on correlation studies, selection based on EL of inbred lines under drought conditions was not recommended. Moisture stress just prior to and during flowering caused spotty abortion of kernels. Thus, EL did not adequately reflect KPR and subsequent yield potential. The correlations of EL with Y and ear components of yield in 1981, the season with moisture stress before and during flowering, were primarily between SCA effects.

Under the conditions of 1981, selection for specific hybrid combinations and not specific inbreds would be effective. The means of KPR reflected differences in Y more closely than did the means of EL.

A similar predomination of correlations between SCA effects occurred with KD in 1982. Both EL in 1981 and KD in 1982 exhibited response to planting density as shown by correlations between GCA effects. This response, no doubt, contributed to the low average correlations of GCA effects relative to SCA effects.

Exceptionally high yielding lines like Va17 and specific crosses like A619 X A632 were determined to be exceptional because they combined high genetic potential for a number of ear components. Although grain yield components, such as KRN and KPR, may be negatively correlated, it is not impossible to get good potential for a number of components in the same hybrid. A balanced expression of ear components was considered necessary for maximum yield.

An ideotype of maize which could be applied to selection in a breeding nursery included a girthy, high-kernel-row-numbered ear with many long, narrow kernels, growing on a plant that does not delay silking much under population or drought stress. Selection will be most effective in a poor season and at high populations.

No evidence was found for considering pollen availabilities a factor in seed set. Female floret abortion was more sensitive to environment than pollen shed after silk emergence.

GCA-variance-to-SCA-variance ratios were generally higher in 1981 under moisture stress. This suggested an association between SCA and adaptation to sub-optimum environments. GCA-variance-to-SCA-variance ratios were found to increase slightly when data were combined over years. The influence of SCA effects in producing stable grain yields was apparent.

Planting density must be optimum or above optimum for yield before effective increases in heritability of flowering and ear traits will be realized. Under the high density treatment in this study, selection for grain yield based on ear traits would be made more efficient by increased heritabilities of the ear traits and not by improvements in genetic correlations. The small influence of plant environment on KPR suggested that it would be a good trait on which to base selection for stable grain yield. The traits most important to stable yield were KPR, KD, and KRN.

Hybrid-by-year interactions were highly significant for all flowering and ear traits. Data combined over seasons was better for discerning differences among hybrids than was data taken at 69,000 pl/ha.

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APPENDIX

Table A1. Analyses of variance of flowering and ear traits for 66 hybrids(12-parent diallel) grown at 39,536 plants per hectare in 1981.

Source	d.f.	Mean squares for indicated trait <sup>a</sup>									
		DSD	ASE	EL	KN	KD	Y	AY			
Rep	2	6.794	11.348	18.948	50967	3.803	14.043	13.536			
Hybrid	65	7.181**	7.175**	10.342**	21658**	1.413**	2.896**	2.752**			
GCA	11	28.174**	30.411**	38.287**	77660**	3.657**	6.425**	6.011**			
SCA	54	2.904**	2.442**	4.649**	10250**	0.957**	2.178**	2.089**			
Error 1	130	1.321	1.165	1.842	4375	0.498	1.122	1.139			
C.V.		31.274	19.635	7.465	11.065	7.293	16.838	16.936			

<sup>a</sup> Trait codes as defined in Table 2.

\*\*\* Significant at the 0.05, and 0.01 probability level, respectively.



**Table A2. Analyses of variance of flowering and ear traits for 66 hybrids (12-parent diallel) grown at 49,420 plants per hectare in 1981.**

Source	d.f.	Mean squares for indicated trait <sup>a</sup>									
		DSD	ASE	EL	KN	KD	Y	AY			
Rep	2	2.445	1.099	12.033	24774	6.385	11.308	10.897			
Hybrid	65	7.756**	5.846**	9.035**	15515**	1.207**	2.958**	2.873**			
GCA	11	30.988**	24.496**	41.763**	56507**	3.603**	7.731**	7.643**			
SCA	54	3.023**	2.047**	2.368**	7165*	0.719	1.985	1.901			
Error 1	130	0.884	0.755	1.301	4654	0.563	1.390	1.385			
C.V.		24.196	16.900	6.816	12.651	7.837	17.482	17.434			

<sup>a</sup> Trait codes as defined in Table 2.  
 \*\*, \* Significant at the 0.05, and 0.01 probability level, respectively.

Table A3. Analyses of variance of flowering and ear traits for 66 hybrids (12-parent diallel) grown at 59,304 plants per hectare in 1981.

Source	d.f.	Mean squares for indicated trait <sup>a</sup>										
		DSD	ASE	EL	KN	KD	Y	AY	Y	Y	AY	
Rep	2	4.186	7.949	8.163	19936	1.294	9.025	7.410				
Hybrid	65	11.483**	9.443**	10.141**	20366**	1.679**	5.728**	5.085**				
GCA	11	51.207**	40.791**	40.697**	75724**	6.202**	15.025**	13.158**				
SCA	54	3.391**	3.058**	3.916**	9089**	0.758**	3.835**	3.441**				
Error 1	130	1.756	1.175	1.363	4712	0.410	1.604	1.642				
C.V.		29.345	22.549	7.265	13.592	6.857	17.373	17.453				

<sup>a</sup> Trait codes as defined in Table 2.

\*,\*\* Significant at the 0.05, and 0.01 probability level, respectively.

Table A4. Analyses of variance of flowering and ear traits for 66 hybrids (12-parent diallel) grown at 69,188 plants per hectare in 1981.

Source	d. f.	Mean squares for indicated trait <sup>a</sup>												
		DSD	ASE	EL	KN	KD	Y	AY	Rep	Hybrid	GCA	SCA	Error 1	C.V.
Rep	2	6.873	3.873	0.759	4726	0.003	2.204	0.478						
Hybrid	65	16.483**	11.778**	8.909**	16296**	1.289**	4.630**	4.065**						
GCA	11	79.072**	52.620**	33.888**	52614**	4.562**	12.781**	9.963**						
SCA	54	3.733**	3.459**	3.821**	8898*	0.623	2.968*	2.863*						
Error 1	130	1.846	1.438	1.217	5889	0.437	2.067	1.815						
C.V.		26.275	28.677	7.689	18.033	7.337	22.308	20.510						

<sup>a</sup> Trait codes as defined in Table 2.

\*,\*\* Significant at the 0.05, and 0.01 probability level, respectively.

**Table A5. Analyses of variance of flowering and ear traits for 66 hybrids (12-parent diallel) grown at 39,536 plants per hectare in 1982.**

Source	d.f.	Mean squares for indicated trait <sup>a</sup>							
		KN	KM	KD	KTH	Y	AY		
Rep	2	3073	0.601	2.920	0.288	0.310	0.204		
Hybrid	65	18383**	1.622**	1.190**	0.225**	3.254**	3.094**		
GCA	11	80126**	8.866**	4.487**	1.006**	11.563**	10.953**		
SCA	54	5806**	0.146*	0.519*	0.066*	1.562**	1.493**		
Error 1	130	2683	0.100	0.329	0.042	0.538	0.530		
C.V.		7.710	4.105	4.937	4.580	8.059	7.989		

<sup>a</sup> Trait codes as defined in Table 2.

\*,\*\* Significant at the 0.05, and 0.01 probability level, respectively.

**Table A6. Analyses of variance of flowering and ear traits for 66 hybrids (12-parent diallel) grown at 49,420 plants per hectare in 1982.**

Source	d.f.	Mean squares for indicated trait <sup>a</sup>							
		KN	KM	KD	KTH	Y	AY		
Rep	2	1826	0.127	1.198	0.510	0.012	0.012	0.012	
Hybrid	65	20695**	1.657**	1.160**	0.227**	4.723**	4.723**	4.723**	
GCA	11	99492**	9.231**	3.947**	0.888**	20.338**	20.338**	20.338**	
SCA	54	4644*	0.115	0.593**	0.093**	1.542*	1.542*	1.542*	
Error 1	130	3221	0.090	0.278	0.047	1.003	1.003	1.003	
C.V.		9.194	3.866	4.592	4.874	9.772	9.772	9.772	

<sup>a</sup> Trait codes as defined in Table 2.

\*,\*\* Significant at the 0.05, and 0.01 probability level, respectively.

**Table A7. Analyses of variance of flowering and ear traits for 66 hybrids (12-parent diallel) grown at 59,304 plants per hectare in 1982.**

Source	d.f.	Mean squares for indicated trait <sup>a</sup>							
		KN	KM	KD	KTH	Y	AY		
Rep	2	2005	0.196	0.819	0.857	4.183	3.603		
Hybrid	65	18856**	1.692**	1.167**	0.216**	5.570**	5.626**		
6CA	11	85415**	9.120**	4.216**	0.862**	20.682**	21.015**		
SCA	54	5297**	0.179**	0.546*	0.085*	2.492**	2.491**		
Error 1	130	2992	0.091	0.346	0.054	1.457	1.386		
C.V.		9.576	3.920	5.191	5.194	10.953	10.671		

<sup>a</sup> Trait codes as defined in Table 2.

\*,\*\* Significant at the 0.05, and 0.01 probability level, respectively.

Table A8. Analyses of variance of flowering and ear traits for 66 hybrids (12-parent diallel) grown at 59,188 plants per hectare in 1982.

Source	d.f.	Mean squares for indicated trait <sup>a</sup>							
		KN	KN	KD	KTH	Y	AY		
Rep	2	7025	0.442	1.628	0.778	10.641	9.628		
Hybrid	65	17859**	1.671**	0.958**	0.250**	7.389**	7.342**		
GCA	11	83951**	8.939**	2.909**	0.983**	28.309**	28.130**		
SCA	54	4396**	0.190*	0.561*	0.101**	3.128**	3.107**		
Error 1	130	2277	0.121	0.347	0.048	1.664	1.541		
C.V.		9.068	4.523	5.265	4.933	11.271	10.812		

<sup>a</sup> Trait codes as defined in Table 2.

\*,\*\* Significant at the 0.05, and 0.01 probability level, respectively.

Table A9. Analyses of variance of flowering and ear traits for 66 hybrids (12-parent diallel) grown at 39,536 plants per hectare combined over years.

Source	d. f.	Mean squares for indicated traits <sup>a</sup>										
		OSD	ASE	EL	KN	KRN	KM	KD	Y	AY		
Year	1	822.788**	32.348	81.274	543081*	15.760**	57.031**	375.863**	781.523**	764.695**		
Repl/Year <sup>1</sup>	4	3.487	5.778	11.763	27020	0.673	1.370	3.361	7.177	6.870		
Hybrid	65	5.427**	6.309**	19.928**	30505**	16.681**	2.714**	1.935**	3.528**	3.332**		
GCA	11	23.462**	28.280**	99.312**	137609**	90.908**	15.107**	7.325**	11.320**	10.753**		
SCA	54	1.753**	1.833**	3.758**	8667**	1.560**	0.189**	0.837**	1.941**	1.821**		
Hybrid X Year	65	3.002**	2.645**	4.967**	9536**	0.771**	0.240**	0.669**	2.622**	2.519**		
Error 1	240	0.777	0.763	1.499	3529	0.498	0.107	0.413	0.830	0.835		
C.V.		39.460	15.109	6.571	9.358	4.402	4.459	6.039	11.838	11.651		

<sup>a</sup> Trait codes as defined in Table 2.

\*,\*\* Significant at the 0.05, and 0.01 probability level, respectively.



Table A10. Analyses of variance of flowering and ear traits for 66 hybrids (12-parent diallel) grown at 49,420 plants per hectare combined over years.

Source	d. f.	Mean squares for indicated trait <sup>2</sup>										
		DSD	ASE	EL	KN	KRN	KM	KD	Y	AY		
Year	1	814.965**	46.152**	114.353*	603340**	38.453**	80.550**	362.347**	3217.746**	1213.356**		
Repl(Year)	4	1.276	1.173	7.171	13300	0.292	1.187	3.792	5.660	5.455		
Hybrid	65	6.035**	5.051**	20.321**	2797**	15.447**	2.663**	1.812**	5.135**	5.065**		
GCA	11	25.357**	21.327**	105.430**	128330**	85.099**	14.716**	7.087**	18.909**	18.835**		
SCA	54	2.100**	1.735**	2.984**	7534**	1.258**	0.208**	0.738**	2.329**	2.260**		
Hybrid X Year	65	3.256**	2.290**	3.776**	8233**	0.946**	0.250**	0.556	2.546**	2.531**		
Error 1	260	0.589	0.587	1.314	3937	0.559	0.094	0.421	1.197	1.194		
C.V.		31.316	13.967	6.638	10.851	4.740	4.198	6.159	12.873	12.855		

<sup>2</sup> Trait codes as defined in Table 2.

\*\* Significant at the 0.05, and 0.01 probability level, respectively.

Table A11. Analyses of variance of flowering and ear traits for 66 hybrids (12-parent diallel) grown at 59,304 plants per hectare combined over years.

Source	d. f.	Mean squares for indicated trait <sup>a</sup>									
		DSD	ASE	EL	KN	KRN	KH	KD	Y	AY	
Year	1	1065.410**	59.386*	29.455	433247**	44.535**	84.966**	394.202**	1377.631**	1367.927**	
Repl(Year)	4	3.335	5.403	11.314	10970	0.677	0.849	1.056	6.604	5.506	
Hybrid	65	8.010**	6.781**	19.919**	31290**	14.931**	2.512**	2.238**	8.485**	7.954**	
GCA	11	36.486**	30.484**	99.812**	144464**	79.740**	13.652**	9.135**	28.749**	27.138**	
SCA	54	2.209**	1.953**	3.645**	8237**	1.729**	0.242**	0.833**	4.357**	4.046**	
Hybrid X Year	65	5.121**	4.218**	3.837**	7931**	0.790*	0.288**	0.608**	2.814**	2.758**	
Error 1	260	0.986	0.727	1.253	5852	0.535	0.099	0.378	1.531	1.514	
C.V.		34.533	16.415	6.850	11.534	4.671	4.348	5.949	13.513	13.393	

<sup>a</sup> Trait codes as defined in Table 2.

\*,\*\* Significant at the 0.05, and 0.01 probability level, respectively.

Table A12. Analyses of variance of flowering and ear traits for 66 hybrids (12-parent diallel) grown at 69,188 plants per hectare combined over years.

Source	d. f.	Mean squares for indicated trait <sup>a</sup>										
		DSD	ASE	EL	KN	KRN	KM	KD	Y	AV		
Year	1	814.965**	46.152**	114.353*	603360**	38.453**	80.550**	362.347**	1217.746**	1213.356**		
Rep(Year)	4	1.276	1.173	7.171	13300	0.292	1.187	3.792	5.660	5.455		
Hybrid	65	6.035**	5.051**	20.321**	27977**	15.447**	2.663**	1.812**	5.135**	5.065**		
GCA	11	25.357**	21.327**	105.430**	128330**	85.099**	14.716**	7.087**	18.909**	18.835**		
SCA	54	2.100**	1.735**	2.984**	7534**	1.258**	0.208**	0.738**	2.329**	2.260**		
Hybrid X Year	65	3.256**	2.290**	3.776**	8233**	0.946**	0.250**	0.556*	2.546**	2.531**		
Error 1	260	0.589	0.587	1.314	3937	0.559	0.094	0.421	1.197	1.194		
C.V.		31.316	13.967	6.638	10.851	4.740	4.198	6.159	12.873	12.855		

<sup>a</sup> Trait codes as defined in Table 2.

\*\* Significant at the 0.05, and 0.01 probability level, respectively.

Table A13. Days from planting to first pollen shed (above diagonal) and days of silking delay (below diagonal), averaged over densities and years, for 66 hybrids (12-parent diallel) and averages for the hybrids having the indicated inbred as a common parent.

Inbred lines	Day to first pollen shed and days of silking delay for indicated hybrid												Average
	Va.79:419	A619	A632	B73	H93	Mo17	Va17	H60	Pa91	H96	Oh78	Va85	
Va.79:419		73.6	76.2	77.2	78.4	76.5	76.0	75.3	78.2	77.8	80.1	74.9	76.7
A619	3.34		74.3	79.1	77.0	74.4	75.5	74.4	77.0	77.7	77.1	74.9	75.9
A632	1.84	2.06		79.0	78.8	76.9	77.6	77.1	78.7	78.5	81.0	77.1	77.7
B73	2.37	2.68	1.36		80.9	79.3	79.8	78.4	80.5	82.0	81.8	78.4	79.7
H93	2.13	2.71	1.05	1.63		78.4	80.1	78.7	80.0	81.1	81.6	79.1	79.5
Mo17	3.13	5.28	2.39	2.24	2.81		79.2	77.4	79.2	80.5	79.7	77.6	78.1
Va17	1.80	3.17	2.33	1.71	2.19	2.64		78.7	80.5	81.0	80.9	78.5	78.9
H60	4.43	5.62	3.04	2.78	3.22	4.12	3.10		79.0	79.5	80.4	78.1	77.9
Pa91	2.56	5.89	2.13	2.20	2.29	3.43	2.70	4.07		81.6	83.0	79.7	79.8
H96	2.01	3.04	.71	1.00	1.42	3.20	1.09	2.26	1.97		81.7	79.0	80.0
Oh78	2.87	3.48	1.85	2.76	2.63	2.96	2.53	3.95	2.76	2.57		81.7	80.8
Va85	3.43	5.21	2.33	2.47	2.37	3.63	2.33	3.43	2.74	1.72	2.94		78.1
Average	2.72	3.86	1.92	2.11	2.22	3.26	2.33	3.64	2.93	1.91	2.85	2.96	
											Overall means	2.73	78.6

Table A14. Estimates of GCA effects, SCA effects, and SCA variances of days from planting to first pollen shed (above diagonal) and days of silking delay (below diagonal), averaged over planting densities and years, for inbreds and hybrids from a twelve-parent diallel of maize.

Inbred lines	SCA effects													GCA effects	SCA variances
	Va.79:419	A619	A632	B73	H93	Mo17	Va17	H60	Pa91	H96	Ch7B	Va85			
Va.79:419	0.03	0.59	-0.57	0.88	0.45	-0.92	-0.53	0.36	-0.33	1.12	-1.06	-2.04	0.50		
A619	-0.62	-0.41	2.25	0.46	-0.73	-0.42	-0.50	0.04	0.48	-0.98	-0.22	-2.97	0.73		
A632	0.02	-1.02	0.15	0.22	-0.19	-0.42	0.18	-0.27	-0.78	0.90	0.03	-0.93	0.20		
B73	0.33	-0.61	0.20	0.13	0.08	-0.27	-0.62	-0.55	0.62	-0.40	-0.82	1.18	0.70		
H93	-0.03	-0.71	-0.23	0.14	-0.59	0.22	-0.10	-0.83	-0.07	-0.44	0.12	0.95	0.20		
Mo17	-0.17	0.73	-0.03	-0.39	0.05	0.80	0.11	-0.10	0.85	-0.79	0.10	-0.54	0.28		
Va17	-0.47	-0.37	0.93	0.10	0.46	-0.23	0.59	0.25	0.51	-0.44	0.10	0.32	0.25		
H60	0.72	0.64	0.21	-0.27	0.05	-0.18	-0.14	0.07	0.18	0.68	0.40	1.30	0.16		
Pa91	-0.43	1.64	0.02	-0.12	-0.15	0.14	0.07	-0.13	-0.90	-0.63	1.57	0.32	0.32		
H96	0.19	-0.03	-0.22	-0.14	0.15	0.79	-0.29	-0.57	0.61	1.14	2.47	0.64	0.64		
Ch7B	0.02	-0.62	-0.12	0.58	0.33	-0.48	0.12	0.09	-0.37	0.61	-0.17	-0.55	0.51		
Va85	0.45	0.98	0.24	0.16	-0.06	0.06	-0.22	-0.56	-0.52	-0.36	-0.17	-0.55	0.51		
GCA effects	-0.01	1.25	-0.89	-0.68	-0.56	0.58	-0.44	1.00	0.27	-0.90	0.13	0.26	0.26		
SCA variances	0.14	0.72	0.19	0.09	0.07	0.14	0.14	0.15	0.31	0.14	0.14	0.18	0.18		

**Table A15. Duration of pollen shed in days (above diagonal) and days of pollen shed after first silk emergence (below diagonal), averaged over planting densities and years, for 66 hybrids (12-parent diallel) and averages for the hybrids having the indicated inbred as a common parent.**

Days of pollen shed and days of pollen shed after silk emergence for indicated hybrid													
Inbred lines	Va.79:419	A619	A632	B73	H93	Mo17	Va17	H60	Pa91	H96	Oh7B	Va85	Average
Va.79:419		9.1	8.1	8.4	9.0	8.6	8.4	10.2	9.3	9.1	9.0	8.5	8.9
A619	5.78		7.7	7.9	8.5	8.0	8.3	8.6	9.3	8.4	8.7	7.8	8.4
A632	6.22	5.68		7.4	6.9	7.6	7.2	8.1	8.1	7.5	8.0	7.1	7.6
B73	6.05	5.17	6.03		7.4	6.9	7.7	8.0	8.2	7.5	8.3	7.2	7.7
H93	6.84	5.79	5.89	5.81		7.7	7.5	8.5	8.3	7.4	8.4	7.4	7.9
Mo17	5.45	2.73	5.25	4.67	4.93		7.3	8.1	8.1	7.9	7.9	6.7	7.7
Va17	6.61	5.18	4.87	5.96	5.35	4.63		7.6	8.0	7.6	7.4	6.9	7.6
H60	5.73	2.94	5.07	5.23	5.28	4.02	4.49		8.8	8.4	8.7	7.9	8.4
Pa91	6.78	3.41	6.02	6.00	6.03	4.64	5.32	4.69		8.1	8.6	7.8	8.4
H96	7.13	5.40	6.83	6.49	5.99	4.73	6.50	6.10	6.18		8.2	7.3	8.0
Oh7B	6.17	5.24	6.10	5.49	5.73	4.91	4.91	4.72	5.86	5.66		7.4	8.2
Va85	5.04	2.61	4.73	4.73	5.01	3.08	4.56	4.43	5.07	5.63	4.43		7.4
Average	6.16	4.54	5.70	5.60	5.70	4.46	5.31	4.79	5.45	6.06	5.38	4.48	
Overall means												5.30	8.03

Table A16. Estimates of GCA effects, SCA effects, and SCA variances of duration of pollen shed in days (above diagonal) and days of pollen shed after first silk emergence (below diagonal), averaged over planting densities and years, for inbreds and hybrids from a twelve-parent diallel of maize.

		SCA effects												SCA effects variances	
Inbred lines		Va.79:419	A619	A632	B73	H93	Mo17	Va17	H60	Pa91	H96	Ch7B	Va85	GCA	SCA
Va.79:419			-0.250	-0.451	-0.198	0.131	-0.043	-0.120	0.755	-0.065	0.247	-0.152	0.145	0.937	0.089
A619	0.37		-0.239	-0.235	0.185	-0.080	0.343	-0.316	0.423	0.076	0.069	0.024	0.408	0.408	0.049
A632	-0.47	0.79		0.163	-0.509	0.418	0.058	0.099	0.130	0.041	0.159	0.131	-0.458	0.066	0.066
B73	-0.53	0.37	-0.04		-0.114	-0.420	0.428	-0.106	0.083	-0.114	0.354	0.159	-0.353	0.054	0.054
H93	0.16	0.90	-0.28	-0.26		0.175	0.073	0.156	-0.022	-0.427	0.241	0.112	-0.123	0.051	0.051
Mo17	0.13	-0.81	0.44	-0.03	0.12		0.025	0.016	-0.045	0.316	-0.033	-0.328	-0.349	0.047	0.047
Va17	0.36	0.71	-0.87	0.32	-0.39	0.25		-0.436	-0.014	0.073	-0.368	-0.063	-0.439	0.053	0.053
H60	0.04	-0.96	-0.11	0.16	0.11	0.21	-0.25		-0.148	-0.036	-0.019	0.036	0.437	0.080	0.080
Pa91	0.37	-1.22	0.11	0.20	0.13	0.10	-0.16	-0.21		-0.255	-0.071	-0.016	0.439	0.017	0.017
H96	0.05	0.11	0.27	0.03	-0.57	-0.48	0.36	0.53	-0.12		0.049	0.029	-0.073	0.031	0.031
Ch7B	-0.17	0.69	0.27	-0.23	-0.09	0.45	-0.49	-0.11	0.30	-0.56		-0.229	0.218	0.030	0.030
Va85	-0.31	-0.95	-0.11	0.00	0.17	-0.39	0.15	0.60	0.50	0.39	-0.06		-0.645	0.025	0.025
GCA effects	0.95	-0.84	0.43	0.33	0.43	-0.93	0.00	-0.56	0.17	0.83	0.09	-0.90			
SCA variances	0.08	0.64	0.18	0.05	0.13	0.13	0.20	0.15	0.19	0.13	0.13	0.18			

Table A17. Ear length in centimeters (above diagonal) and kernels per row on the ear (below diagonal), averaged over planting densities and years, for 66 hybrids (12-parent diallel) and averages for the hybrids having the indicated inbred as a common parent.

Inbred lines	Ear length (cm) and kernels per row for indicated hybrid											Average	
	Va.79:419	A619	A632	B73	H93	Mo17	Va17	H60	Pa91	H96	Oh7B		Va85
Va.79:419		12.2	14.5	13.5	14.2	15.9	14.1	13.2	14.5	13.8	14.3	14.3	14.1
A619	27.1		17.1	15.4	15.6	17.1	16.4	15.7	14.6	15.5	17.5	15.3	15.7
A632	31.0	34.9		16.5	16.3	19.0	16.9	17.3	17.4	17.0	17.7	17.3	17.0
B73	31.1	33.6	36.2		16.1	18.7	17.8	18.3	17.1	16.1	16.7	17.5	16.7
H93	31.8	31.3	34.5	37.3		19.0	17.2	18.0	16.2	15.9	16.7	17.0	16.6
Mo17	35.9	30.8	38.6	40.9	39.7		20.2	18.7	20.2	17.8	19.7	21.4	18.9
Va17	31.1	32.3	34.3	39.3	36.2	41.6		16.5	17.2	16.2	16.7	18.9	17.1
H60	26.7	28.4	33.6	39.7	35.5	38.1	32.7		17.8	16.9	18.0	17.8	17.1
Pa91	30.5	27.2	37.2	38.3	35.8	39.1	34.8	36.4		17.4	17.6	17.8	17.1
H96	32.5	34.7	38.4	38.1	36.8	38.1	38.2	37.4	40.2		17.5	17.3	16.5
Oh7B	33.1	36.1	38.4	40.3	38.9	41.8	36.1	37.1	36.9	42.4		18.5	17.3
Va85	30.6	28.6	34.6	36.3	34.0	42.9	36.8	34.3	34.0	38.1	38.4		17.6
Average	31.0	31.4	35.6	37.4	35.6	38.9	35.8	34.5	35.5	37.7	38.1	35.3	
										Overall means			16.8



Table A18. Estimates of GCA effects, SCA effects, and SCA variances of ear length in centimeters (above diagonal) and kernels per row on the ear (below diagonal), averaged over planting densities and years, for inbreds and hybrids from a twelve-parent diallel of maize.

Inbred lines	SCA effects														GCA effects	SCA variances
	Va.79:419	A619	A632	B73	H93	Mo17	Va17	H60	Pa91	H96	Oh7B	Va85	GCA effects	SCA variances		
Va.79:419	-0.34	0.49	-0.15	0.68	-0.15	0.03	-0.95	0.39	0.38	-0.10	-0.28	-3.01	0.19			
A619	1.16	1.30	-0.04	0.33	-0.72	0.48	-0.16	-1.26	0.25	1.31	-1.14	-1.25	0.71			
A632	0.36	3.95	-0.45	-0.42	-0.30	-0.49	-0.01	0.04	0.33	0.04	-0.54	0.21	0.28			
B73	-1.50	0.68	-1.39	-0.33	-0.29	0.80	1.24	0.06	-0.23	-0.57	-0.03	-0.10	0.27			
H93	1.13	0.29	-1.16	-0.33	0.15	0.34	1.11	-0.65	-0.32	-0.48	-0.41	-0.25	0.29			
Mo17	1.70	-3.82	-0.64	-0.27	0.49	0.76	-0.75	0.82	-1.00	0.03	1.45	2.31	0.54			
Va17	0.29	1.11	-1.53	1.55	0.40	2.17	-0.99	-0.22	-0.60	-1.06	0.95	0.33	0.49			
H60	-2.72	-1.41	-0.91	3.27	0.96	0.06	-1.93	0.38	0.06	0.22	-0.16	0.33	0.51			
Pa91	0.02	-3.65	1.68	0.87	0.26	-0.04	-0.88	2.08	0.68	-0.12	-0.13	0.30	0.32			
H96	-0.45	1.42	0.37	-1.80	-1.16	-3.43	0.05	0.62	2.33	0.44	0.01	-0.33	0.22			
Oh7B	-0.28	2.33	-0.04	-0.11	0.46	-0.19	-2.53	-0.14	-1.42	1.66	0.28	0.61	0.35			
Va85	0.28	-2.06	-0.70	-0.97	-1.33	3.97	1.29	-1.24	0.38	0.25	0.84	0.34				
GCA effects	-4.99	-4.62	0.04	1.98	0.05	3.63	0.21	-1.13	-0.08	2.38	2.82	-0.28				
SCA variances	1.34	5.79	2.36	2.04	0.51	4.82	2.11	2.79	2.87	2.50	1.47	2.43				

Table A19. Ear kernel number, averaged over planting densities and years, for 66 hybrids (12-parent diallel) and averages for the hybrids having the indicated inbred as a common parent.

Inbred lines	Ear kernel number for indicated hybrid												Average	
	Va.79:419	A619	A632	B73	H93	Mo17	Va17	H60	Pa91	H96	Oh7B	Va85		
Va.79:419	475	564	565	551	557	592	428	554	564	607	553	546		
A619		588	568	490	406	538	383	455	549	602	444	500		
A632			596	505	560	584	454	619	573	643	536	566		
B73				548	597	692	564	672	607	722	600	612		
H93					505	568	469	551	544	628	518	534		
Mo17						574	462	559	529	604	588	540		
Va17							481	589	628	627	586	597		
H60								518	509	531	463	478		
Pa91									635	574	542	570		
H96										674	557	579		
Oh7B											628	622		
Va85												547		
Average													Overall mean	556

Table A20. Estimates of GCA effects, SCA effects, and SCA variances of ear kernel number, averaged over planting densities and years, for inbreds and hybrids from a twelve-parent diallel of maize.

Inbred lines	SCA effects													GCA effects	SCA variances
	Va.79:419	A619	A632	B73	H93	Mo17	Va17	H60	Pa91	H96	Ch7B	Va85			
Va.79:419	-7	9	-41	30	30	30	13	-31	-6	-6	-10	19	-11	447	
A619		84	13	21	-70	10	-25	-53	30	36	-39	-63	1913		
A632			-31	-36	12	-16	-26	38	-18	5	-19	10	1193		
B73				-45	-2	41	33	40	-34	33	-6	61	1063		
H93					-9	2	23	5	-13	24	-3	-25	532		
Mo17						2	10	6	-34	-6	61	-18	1024		
Va17							-23	-15	14	-34	6	33	362		
H60								33	14	-11	3	-86	514		
Pa91									40	-69	-18	14	1327		
H96										22	-13	24	563		
Ch7B											10	72	901		
Va85												-11	890		

Table A21. Kernel row number on the ear (above diagonal) and kernel width in millimeters (below diagonal), averaged over planting densities and years, for 66 hybrids (12-parent diallel) and averages for the hybrids having the indicated inbred as a common parent.

Inbred lines	Kernel row number and kernel width (mm) for indicated hybrid												Average
	Va.79:419	A619	A632	B73	H93	Mo17	Va17	H60	Pa91	H96	Oh7B	Va85	
Va.79:419		17.5	18.2	18.3	17.3	15.5	19.0	16.0	18.1	17.3	18.3	18.0	17.6
A619	7.11		16.8	16.9	15.6	13.3	16.7	13.5	16.7	15.8	16.7	15.6	15.9
A632	6.19	6.91		16.4	14.6	14.5	16.9	13.6	16.6	14.9	16.8	15.5	15.9
B73	6.58	7.32	6.70		14.7	14.6	17.6	14.2	17.6	16.0	18.0	16.5	16.4
H93	6.79	7.81	7.35	7.71		12.7	15.7	13.2	15.4	14.8	16.2	15.2	15.0
Mo17	7.13	7.73	7.09	7.46	8.35		13.8	12.2	14.3	13.9	14.5	13.8	13.9
Va17	6.32	7.24	6.47	6.59	7.49	7.66		14.7	16.9	16.5	17.4	15.9	16.4
H60	7.40	8.79	7.98	8.34	8.72	8.74	7.78		14.2	13.6	14.4	13.6	13.9
Pa91	6.64	7.12	6.66	6.83	7.64	7.59	6.87	8.21		15.8	15.6	15.9	16.1
H96	6.69	7.68	7.24	7.29	7.64	7.64	6.99	8.16	7.51		15.9	14.6	15.4
Oh7B	6.07	7.06	6.35	6.28	7.06	6.97	6.37	7.57	6.69	6.77		16.4	16.4
Va85	6.46	7.38	6.72	6.95	7.69	7.83	6.83	8.22	7.17	7.54	6.62		15.5
Average	6.67	7.47	6.88	7.09	7.66	7.65	6.96	8.17	7.18	7.38	6.71	7.22	
										Overall means	7.25	7.22	15.7

Table A22. Estimates of GCA effects, SCA effects, and SCA variances of ear kernel row number (above diagonal) and kernel width in millimeters(below diagonal), averaged over planting densities and years, for inbreds and hybrids from a twelve-parent diallel of maize.

SCA effects														SCA	
Inbred lines	Va.79:419	A619	A632	B73	H93	Mo17	Va17	H60	Pa91	H96	Ch7B	Va85	GCA effects	SCA variances	
Va.79:419		-0.52	0.21	-0.32	0.25	-0.27	0.44	0.21	-0.15	-0.11	-0.18	0.43	2.07	0.09	
A619	0.26		0.66	0.19	0.45	-0.68	-0.09	-0.45	0.37	0.21	0.01	-0.16	0.22	0.17	
A632	-0.01	-0.17		-0.25	-0.55	0.58	0.14	-0.38	0.30	-0.61	0.14	-0.26	0.19	0.17	
B73	0.15	0.01	0.03		-1.04	0.06	0.29	-0.35	0.63	-0.18	0.74	0.21	0.79	0.23	
H93	-0.27	-0.12	0.06	0.19		-0.26	-0.11	0.24	-0.04	0.16	0.49	0.41	-0.75	0.20	
Mo17	0.08	-0.20	-0.19	-0.06	0.21		-0.71	0.37	0.10	0.56	0.02	0.22	-1.98	0.18	
Va17	0.03	0.07	-0.05	-0.17	0.11	0.28		0.11	-0.02	0.30	0.11	-0.46	0.81	0.10	
H60	-0.22	0.29	0.13	0.24	0.01	0.03	-0.17		0.05	0.24	-0.07	-0.03	-1.95	0.06	
Pa91	0.11	-0.28	-0.09	-0.16	0.02	-0.01	0.02	0.03		0.07	-1.27	-0.04	0.43	0.21	
H96	-0.06	0.05	0.27	0.07	-0.20	-0.19	-0.08	-0.25	0.21		-0.13	-0.52	-0.37	0.11	
Ch7B	0.05	0.17	0.11	-0.20	-0.04	-0.13	0.03	-0.09	0.11	-0.02		0.14	0.72	0.23	
Va85	-0.12	-0.07	-0.08	-0.09	0.03	0.17	-0.07	0.00	0.04	0.19	0.00		-0.18	0.23	
GCA effects	-0.64	0.24	-0.41	-0.17	0.44	0.44	-0.32	1.01	-0.08	0.14	-0.60	-0.04			
SCA variances	0.02	0.03	0.02	0.02	0.02	0.03	0.01	0.03	0.02	0.03	0.01	0.01	0.01	0.01	

Table A23. Kernel depth in millimeters (above diagonal) and kernel thickness in millimeters (below diagonal), averaged over planting densities and years, for 66 hybrids (12-parent diallel) and averages for the hybrids having the indicated inbred as a common parent.

Inbred lines	Kernel depth (mm) and kernel thickness (mm) for indicated hybrid												Average
	Va.79:419	A619	A632	B73	H93	Mo17	Va17	H60	Pa91	H96	Oh78	Va85	
Va.79:419	10.4	10.0	11.0	11.0	11.0	10.0	10.5	9.8	10.6	10.5	10.6	10.5	10.4
A619	4.60	10.3	10.1	10.2	9.4	10.1	10.1	9.6	9.9	10.8	10.2	9.5	10.1
A632	4.75	4.94	10.7	10.7	10.6	10.8	10.8	9.5	10.0	10.4	10.5	9.9	10.3
B73	4.39	4.61	4.55	10.8	10.7	11.6	10.4	11.3	11.1	11.1	11.1	10.4	10.8
H93	4.51	5.03	4.77	4.35	10.9	11.6	9.9	11.2	11.2	11.2	10.7	10.0	10.7
Mo17	4.51	6.38	4.95	4.65	4.81	10.3	9.2	10.3	9.9	10.2	10.2	10.0	10.1
Va17	4.58	5.16	5.03	4.55	4.80	5.01	10.4	10.2	11.0	10.9	10.9	10.0	10.7
H60	5.03	5.86	5.31	4.66	5.14	5.03	5.39	9.6	10.5	10.1	9.4	9.8	
Pa91	4.82	5.51	4.67	4.55	4.55	5.26	4.98	4.98	11.0	10.1	10.5	10.4	
H96	4.29	4.54	4.44	4.25	4.32	4.77	4.29	4.54	4.37	10.7	10.6	10.7	
Oh78	4.35	4.92	4.63	4.18	4.33	4.88	4.69	4.92	4.88	4.14	10.8	10.5	
Va85	4.90	5.53	5.02	4.85	5.01	5.04	5.19	5.33	5.33	4.55	4.86	10.1	
Average	4.61	5.19	4.82	4.51	4.69	5.03	4.88	5.11	4.90	4.41	4.62	5.05	10.4
										Overall means	4.82	10.4	

Table A24. Estimates of GCA effects, SCA effects, and SCA variances of kernel depth in millimeters(above diagonal) and kernel thickness in millimeters(below diagonal), averaged over planting densities and years, for inbreds and hybrids from a twelve-parent diallel of maize.

SCA effects														
Inbred lines	Va.79:419	A619	A632	B73	H93	Mo17	Va17	H60	Pa91	H96	Ch7B	Va85	GCA effects	SCA variances
Va.79:419		0.349	-0.342	0.084	0.197	-0.186	-0.195	-0.030	0.098	-0.301	-0.004	0.329	0.040	0.049
A619	-0.398		0.414	-0.394	-0.144	-0.306	-0.169	0.146	-0.192	0.438	0.056	-0.199	-0.386	0.081
A632	0.148	-0.293		-0.051	-0.005	0.558	0.224	-0.224	-0.312	-0.191	0.048	-0.119	-0.099	0.078
B73	0.140	-0.272	0.070		-0.438	0.100	0.387	0.136	0.426	-0.090	0.057	-0.218	0.483	0.070
H93	0.056	-0.056	0.087	0.007		0.446	0.504	-0.306	0.372	0.127	-0.239	-0.514	0.371	0.120
Mo17	-0.309	0.920	-0.100	-0.054	-0.100		-0.062	-0.314	0.135	-0.548	-0.026	0.203	-0.309	0.104
Va17	-0.079	-0.128	0.135	0.001	0.051	-0.102		0.277	-0.486	-0.044	0.011	-0.447	0.287	0.097
H60	0.122	0.314	0.165	-0.135	0.140	-0.334	0.188		-0.196	0.404	0.206	-0.099	-0.611	0.054
Pa91	0.141	0.196	-0.241	-0.012	-0.221	0.122	0.003	-0.251		0.208	-0.433	0.379	0.027	0.106
H96	0.151	-0.236	0.069	0.227	0.089	0.169	-0.146	-0.149	-0.089		-0.182	0.180	0.331	0.084
Ch7B	-0.016	-0.086	0.023	-0.082	-0.127	0.057	0.029	0.005	0.195	-0.004		0.506	0.147	0.051
Va85	0.043	0.040	-0.064	0.111	0.073	-0.267	0.047	-0.065	0.158	-0.082	0.006		-0.282	0.026
GCA effects	-0.226	0.407	0.006	-0.340	-0.140	0.230	0.066	0.320	0.088	-0.451	-0.222	0.261		
SCA variances	0.031	0.133	0.019	0.014	0.007	0.115	0.006	0.036	0.026	0.018	0.002	0.008		

**Table A25. Grain yield in megagrams per hectare adjusted to remove the effects of barrenness (above diagonal) and grain yield in megagrams per hectare (below diagonal), averaged over planting densities and years, for 66 hybrids (12-parent diallel) and averages for the hybrids having the indicated inbred as a common parent.**

Adjusted grain yield and grain yield (Mg/ha) for indicated hybrid														
Inbred lines	Va.79:419	A619	A632	B73	H93	Mo17	Va17	H60	Pa91	H96	Oh7B	Va85	Average	
Va.79:419		6.7	7.6	8.0	8.2	7.6	8.3	6.7	8.1	7.5	7.2	7.5	7.6	
A619	6.4		9.2	8.6	8.3	6.5	8.9	7.6	7.2	8.4	9.0	6.7	7.9	
A632	7.6	9.0		8.3	8.4	8.9	8.9	7.8	9.2	9.0	8.7	7.8	8.5	
B73	7.9	8.6	8.3		8.7	9.5	10.6	10.0	10.3	9.2	9.4	9.2	9.3	
H93	8.2	8.3	8.4	8.7		8.9	10.0	8.3	9.4	8.9	8.9	9.1	8.8	
Mo17	7.6	6.3	8.8	9.5	8.9		9.6	7.3	8.9	8.1	8.4	10.3	8.5	
Va17	8.3	8.9	8.9	10.6	9.8	9.6		8.4	9.4	9.4	9.1	9.3	9.3	
H60	6.7	7.2	7.8	10.0	8.3	7.3	8.4		8.8	8.6	7.9	8.3	8.2	
Pa91	8.1	7.0	9.1	10.3	9.4	8.9	9.4	8.8		10.2	7.9	9.2	9.0	
H96	7.5	8.4	9.0	9.2	8.9	8.1	9.4	8.6	10.2		8.9	9.0	8.8	
Oh7B	7.1	9.0	8.7	9.3	8.9	8.4	9.1	7.9	7.9	8.9		9.5	8.6	
Va85	7.5	6.6	7.8	9.2	9.1	10.3	9.3	8.3	9.2	9.0	9.5		8.7	
Average	7.5	7.8	8.5	9.2	8.8	8.5	9.2	8.1	8.9	8.8	8.6	8.7	Overall means	8.6



Table A26. Estimates of GCA effects, SCA effects, and SCA variances of grain yield in megagrams per hectare adjusted to remove the effects of barrenness(above diagonal) and grain yield in megagrams per hectare(below diagonal), averaged over planting densities and years, for inbreds and hybrids from a twelve-parent diallel of maize.

		SCA effects												GCA effects	SCA variances
Inbred lines	Va.79:419	A619	A632	B73	H93	Mo17	Va17	H60	Pa91	H96	Oh7B	Va85	GCA effects	SCA variances	
Va.79:419	-0.05	0.22	-0.21	0.48	0.18	0.08	-0.31	0.22	0.22	-0.20	-0.30	-0.11	-1.13	0.04	
A619	-0.15	1.41	0.08	0.21	-1.31	0.31	0.22	-1.08	0.35	1.09	-1.24	-0.76	-0.76	0.76	
A632	0.25	1.40	-0.97	-0.35	0.41	-0.34	-0.21	0.30	0.23	0.13	-0.83	-0.07	-0.07	0.40	
B73	-0.31	0.19	-0.96	-0.87	0.26	0.56	1.20	0.62	-0.43	0.01	-0.25	0.72	0.72	0.39	
H93	0.51	0.32	-0.34	-0.86	0.12	0.40	-0.04	0.14	-0.22	0.00	0.13	0.26	0.26	0.12	
Mo17	0.21	-1.36	0.38	0.27	0.14	0.33	-0.79	-0.03	-0.71	-0.11	1.65	-0.06	-0.06	0.57	
Va17	0.12	0.44	-0.32	0.57	0.22	0.30	-0.42	-0.30	-0.21	-0.26	-0.15	0.74	0.74	0.09	
H60	-0.25	-0.03	-0.17	1.23	-0.08	-0.76	-0.38	0.32	0.21	-0.22	0.04	-0.50	-0.50	0.24	
Pa91	0.26	-1.11	0.23	0.64	0.16	-0.01	-0.35	0.36	0.92	-1.13	0.01	0.39	0.39	0.38	
H96	-0.18	0.38	0.23	-0.44	-0.23	-0.72	-0.21	0.22	0.92	0.06	0.01	0.26	0.26	0.16	
Oh7B	-0.37	1.19	0.13	-0.07	0.00	-0.11	-0.25	-1.12	0.04	0.74	0.02	0.30	0.30	0.30	
Va85	-0.09	-1.27	-0.83	-0.25	0.13	1.65	-0.14	0.06	0.02	-0.01	0.73	0.14	0.14	0.30	
GCA effects	-1.14	-0.86	-0.07	0.74	0.27	-0.05	0.74	-0.51	0.40	0.29	0.04	0.16	0.16	0.16	
SCA variances	0.05	0.83	0.39	0.41	0.11	0.58	0.09	0.23	0.39	0.17	0.32	0.54	0.54	0.54	

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